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Final Technical Memorandum

To:	Carmen White		
From:	Mark Sorensen, Jeff Hess and Rachel Hess		
Date:	December 30, 2011		
Subject:	Conceptual Site Model (CSM) for Carson River Mercury Site, Operable Unit 2		
Contract /TO:	EP-S9-08-03/0024	**ITSI DCN:**	07163.0025.0042

The conceptual site model (CSM) for Operable Unit (OU) 2 is divided into separate discussions by subunit:

- Upper Carson River (OU 2A)
- Lahontan Reservoir (OU 2B)
- Lower Carson River (OU 2C)
- Lahontan Wetlands (OU 2D)

For each subunit, the CSM includes discussions of environmental setting and land use; chemicals of potential concern (COPCs); sources of release; and transformation and transport mechanisms. References for each subunit are provided at the end.

1.0 UPPER CARSON RIVER (OU 2A)

The CSM for the upper Carson River portion (OU 2A) of the Carson River Mercury Site, Nevada, summarizes the sources, release and transport mechanisms, pathways, and ultimate receptors that are affected by mercury (Hg) and methyl mercury (MeHg). The upper Carson River portion encompasses that portion of the Carson River downstream from Carson City, Nevada, and extending to Lahontan Reservoir. Comprehensive discussions of the nature and extent of contamination, and of contaminant fate and transport, will be presented in the remedial investigation (RI) report. This CSM is intended to convey the major themes of Hg distribution, transport, and environmental fate, to support decisions about overall project direction (such as steps that may need to be taken to close any possible data gaps) and to assist in the preliminary screening of remedial alternatives for OU 2.

Fate and transport processes are critical for Hg, because this metal becomes especially hazardous when present in its methylated form; processes of methylation are complex and highly dependent on site-specific conditions that vary substantially across space and time. The CSM also identifies how human and ecological receptors at the site could potentially come into contact with Hg and MeHg present in different environmental media.

1.1 ENVIRONMENTAL SETTING AND LAND USE

The upper Carson River watershed is characterized by land used primarily for rangeland, agricultural farming, and recreational purposes. The river heads in California's eastern Sierra Nevada, south of Lake Tahoe, and flows generally northeasterly into Nevada, ending in the Carson Sink, an enclosed depression. Average annual precipitation in the watershed ranges from 20 to 30 inches in the headwaters area to between 4 and 5 inches near Lahontan Dam and in the Carson Desert. Flow in the portion of the river above Lahontan Reservoir is highly seasonal. Most flow arrives in the spring as snowmelt from the Sierra Nevada, while summer and early fall are quite dry in the arid climate. Based on river flows measured at the Fort Churchill gage about six miles above Lahontan Reservoir, monthly flows during the spring snowmelt season (April through June) average 543 to 1,101 cubic feet per second (cfs), but then decline rapidly to very low values from August through October (ranging from 1 to 38 cfs); flow then increases slightly through the fall and winter months (November through March), until snowmelt starts again in early spring. However, isolated and irregular events of extremely high flows in the river can occur due to rain-on-snow storms during the winter months, when heavy precipitation is augmented by snowmelt (as on January 3-4, 1997, when a record flow of 22,300 cfs was recorded at Fort Churchill). In addition to inflows from the Carson River, the Truckee Canal has provided up to 40% of the annual flows to Lahontan Reservoir at a point not far from the northern terminus of the dam, although these flows have declined in the past few years and are envisioned to comprise an average of 22% of annual Lahontan flows in the future, due to a mandate for increased Truckee River flows to be reserved for Pyramid Lake.

The land in the Carson River portion of the CRMS is largely private land used primarily for rangeland, with some agricultural use along the river. The river is accessible for recreational activities, and most of OU2 is contained within the area considered to host a warm-water fishery, extending from Empire (about five miles upstream from Dayton) to Lahontan Reservoir. The Nevada State Health Division has issued a health advisory, based on Hg contamination, recommending no consumption of any fish caught in the Carson River from Dayton downstream to and including Lahontan Reservoir (http://www.ndow.org/fish/health/, accessed August 25, 2011). However, human exposures to Hg may occur due to consumption of fish along this stretch of the river, despite the health advisory.

1.2 CHEMICALS OF POTENTIAL CONCERN

The primary chemical of potential concern (COPC) for all media in the upper Carson River is Hg, including its methylated form, which is the reason for the comprehensive state health advisory noted in the preceding section. In addition to MeHg, Hg species may occur in many different forms under different conditions. Different species tend to occur in the aqueous phase (e.g., MeHg, dimethyl Hg, reactive Hg [Hg(II)]), sediment/soil (e.g., MeHg, reactive Hg, non-reactive Hg in Hg-silver-gold amalgam), and tissue (e.g., MeHg, ethylmercury). Physical and chemical characteristics and conditions that include oxidation-reduction, the presence of sulfate-reducing bacteria, the presence of organic substrates, and various anions such as sulfate and sulfide, all affect Hg speciation in various media. As discussed in the following section, MeHg generally is detected in water in the river from near Dayton to Lahontan Reservoir and beyond, suggesting that methylation processes can occur in the near-surface environment of the river. Peaks of MeHg in the river have been observed most frequently in late summer, when conditions may be more amenable to methylation, due possibly to (a) increased water temperatures, and (b) lower oxygen levels due to low levels of turbulence and the development of stagnant, isolated pools, owing to very low flow rates at this time of year.

1.3 SOURCES OF RELEASE

The mills along the Carson River and its tributaries have been identified as the primary sources of Hg contamination in the watershed. Since 1860, when local processing of mined ores began and Hg-bearing sediment (in the form of Hg-silver-gold amalgam) began to be released, the Hg-bearing amalgam has been susceptible to erosion and deposition downstream from the points of release near the mills. In addition, some of this Hg apparently has oxidized from metallic Hg (Hg[0]) to a divalent form (Hg2+, referred to as Hg[II]) that generally is more susceptible to transformation to MeHg, which is the biologically active form of the element.

1.3.1 Sediments

Hg concentrations in sediments at and below the mills are much higher than background Hg levels upstream of the mills, where total Hg is mostly less than 200 micrograms per kilogram (ug/kg), or 0.2 milligrams per kilogram (mg/kg) (Hoffman and Thomas, 2000). Hg has been identified in a yellowish silty deposit a few inches to several feet thick in deposits near the mills, where it has been reported to average 99.9 mg/kg (Miller et al., 1998), and in certain mine tailings deposits near the mills, where concentrations range up to 1,610 mg/kg. This Hg-rich material has been eroded and redistributed downstream through the years, especially during high-discharge flooding events capable of eroding alluvial fan or bank sediments. Cooper et al. (1985) estimated that flows of approximately 500 cfs are needed to mobilize Hg-containing sediment in the river system. Such flows occur during the spring snowmelt season (April through June) in most years.

It has been found that in floodplain deposits, Hg is associated with both sand- and silt-sized amalgam grains, in which it is tightly bound and less available for methylation, as well as with the fine-grained, clay-sized fraction of the sediments, in which it tends to be present as a sorbed constituent. In general, total Hg concentrations in channel and floodplain sediments are in the range of about 1 to 25 mg/kg along the stretch of the river from the Empire mill above Dayton to the Carson delta, where the river empties into Lahontan Reservoir. However, Hg concentrations are quite variable and, locally, Hg concentrations in bank sediments range up to more than 100 mg/kg. Studies of floodplain sediments deposited in the 1997 flood have shown that spatially there is a bimodal distribution of Hg across the floodplain: there is a peak in concentrations (averaging 25.4 mg/kg total Hg) within 50 meters of the riverbanks where grain size is relatively coarse, and another peak at > 125 meters from the active channel (averaging 26.4 mg/kg total Hg), where clay is more prevalent; intervening portions of the floodplain had average Hg concentrations between 5.27 and 6.96 ppm (Miller et al., 1999). Within the active channel beginning at the mills above Dayton, Hg concentrations along the length of the river appear to increase somewhat in the downstream direction, at least to Mineral Canyon, a few miles upstream from Fort Churchill; in part, this is due to a greater proportion of fine sediment in some downstream segments of the river system, such as the lower-gradient portions of the river system a short distance above the reservoir (CH2M Hill, 2008).

MeHg in sediments has been analyzed in a subset of the previous studies. It has generally been found to be present at significantly lower levels than total Hg, but concentrations often are well correlated with total Hg; MeHg concentrations range from about 3 ug/kg in sediments upstream from Dayton, to between 5 and 23 ug/kg in sediments downstream from Dayton to near Lahontan Reservoir (Bonzongo et al., 1996a; CH2M Hill, 2008).

Hg in source area soils and sediments near residences in the Dayton area (OU1) was remediated in 1998 and 1999. However, as remediation encompassed a relatively small area, the quantities of Hg transported downstream from the mill-site source areas are not expected to decline significantly for some time to come. Furthermore, because of the widespread distribution of Hg-containing sediments in the floodplain along approximately 40 miles of the river from Dayton to the Lahontan Reservoir, and ongoing erosion in this area, these sediments are expected to be a source of contamination for some time to come, posing risks to the biota and to humans.

1.3.2 Surface Water

Total Hg and MeHg concentrations in the river stretch above Lahontan Reservoir have been fairly well characterized by surface water samples, with some seasonal sampling events as well as an ongoing sampling program conducted by the U.S. Geological Survey (USGS). A variety of studies have reported unfiltered total Hg concentrations averaging from 3 to 10 nanograms per liter (ng/L) in the Carson River or tributaries upstream from Dayton (e.g., Craft et al., 2005). Concentrations increase abruptly near Dayton, with average values for unfiltered total Hg of 51.5 to 120 ng/L near Dayton, and 109 to 1,380 ng/L in a downstream portion near Fort Churchill (Wayne et al., 1996; Bonzongo et al., 1996b). Concentrations of this form of Hg are highly sensitive to suspended sediment load: in samples collected in 1997, the year with the largest recorded flows (due to flooding from a rain-on-snow event on January 3), the average unfiltered total Hg concentration at the Fort Churchill location for January through September was 6,210 ng/L (Hoffman and Taylor, 1998). In the more-comprehensive USGS sampling program, unfiltered Hg concentrations at Weeks Bridge (between Fort Churchill and Lahontan Reservoir) have averaged 2,550 ng/L in 254 samples collected in all seasons of most years from 1997 to 2011 (the median was 1,100 ng/L). Thus unfiltered total Hg concentrations increase downstream in Carson River waters by two to three orders of magnitude. Filtered total Hg follows generally similar patterns, although the increase downstream is only about one order of magnitude.

MeHg in Carson River water samples follows a pattern generally similar to that of total Hg. Upstream of Dayton, limited sampling shows unfiltered MeHg values averaging 0.409 ng/L. Downstream, several studies show higher unfiltered MeHg, averaging 0.505 ng/L and 1.08 ng/L near Dayton (Craft et al., 2005), and averaging 3.11 ng/L (Hoffman and Taylor, 1998) and 4.50 ng/L (Bonzongo et al., 1996b) near Fort Churchill. In the USGS sampling program, unfiltered MeHg concentrations at Weeks Bridge have averaged 2.96 ng/L in 255 samples collected in all seasons from 1997 to 2011 (median was 2.15 ng/L). Thus unfiltered MeHg increases downstream in Carson River waters by about one order of magnitude, significantly less than the increase for unfiltered total Hg. Filtered MeHg also increases downstream, but as observed for filtered total Hg, the increase is not as pronounced as for unfiltered samples.

The various studies show that concentrations of both Hg and MeHg exhibit strong seasonal patterns in Carson River waters. The most complete record is the USGS sampling program, which has encompassed two stations (located at Weeks Bridge and at a second station just below Lahontan Reservoir) sampled roughly monthly (more frequently in the spring and the late summer) from 1997 to the present. Unfiltered total Hg is regularly greater than 1,000 ng/L in most of the spring of each year (March through June); other occurrences above 1,000 ng/L may occur after an intense winter storm. In both cases, peaks of unfiltered total Hg coincide with peak flows, as represented by high total suspended solids (TSS) levels (above about 50 milligrams per liter [mg/L]). In contrast, while unfiltered MeHg also has a springtime peak, generally above 3 ng/L, it also has a somewhat shorter, but nonetheless clear, late-summer peak (in August and September) of about 2 to 11 ng/L. The springtime peak of MeHg, like that of total Hg, is associated with high levels of suspended sediment and high volumetric flow. In contrast, the late-summer MeHg peak occurs when unfiltered total Hg and volumetric flow are low; however, MeHg appears to peak during or shortly after periods when water temperatures exceed 20 degrees Celsius (°C). These seasonal patterns were observed previously, but have been characterized much more thoroughly as a result of the USGS program.

The patterns described above appear to indicate a late-summer period of methylation in the river near or upstream from the Weeks Bridge station, particularly since there is no associated increase in total Hg. This methylation appears plausible because of the sharp decline in river flows after their peak values in May of 1,100 to 1,600 cfs. From July through September, flows are 89-99% lower in the river stretch from Dayton to Fort Churchill, as low as 1 cfs in September at Fort Churchill, about eight miles above Lahontan Reservoir (see Table 2 of Craft et al., 2005). The extended low-flow period in the river in late summer likely results in the creation of localized pools of stagnant water where the concentration of dissolved oxygen (DO) is low and temperatures can increase, enhancing the likelihood of methylation.

Volumetrically, the springtime peak of MeHg appears to be more significant than the late-summer peak, as it often extends for a full three months when flows are the highest of the year; the late-summer MeHg peak values are commonly not as high as those of the spring snowmelt season, and they also do not occur every year. The springtime MeHg peak is distinctive in that it occurs when water temperatures are still relatively low (about 8-18 °C), and is clearly related to periods of high suspended solid levels and high river flows. As a result, this springtime peak of MeHg appears to be related to sediment-bound MeHg; it is likely that Hg-contaminated sediments from the riverbanks or channel already contained MeHg in the solid phase (as documented in CH2M Hill [2008]), and this sediment-bound MeHg was liberated during the high river flows of the spring.

Seasonal patterns are also evident from a water-sampling program conducted by USGS from April 1998 to February 1999 at five locations in the upper Carson River and one location in the upper basin of Lahontan Reservoir about two miles downstream from where the river empties into the reservoir (the latter location is discussed here because it may reflect processes occurring in the river as well as in the upper part of the reservoir). At all locations, after a springtime peak in April and early May, there was a late-summer peak in unfiltered MeHg at each location, generally coinciding with the highest temperatures of the year (17 to 27 °C); peak unfiltered MeHg values were greater than 5 ng/L at the four locations near and downstream from Dayton. The highest MeHg concentrations occurred when high temperatures (> 20 °C) coincided with low dissolved oxygen (DO). At the upper basin reservoir location, DO was 4 mg/L or less from at least July 8 through September 16, while at other times of the year it was generally between 7 and 13 mg/L; during this period of high temperatures, unfiltered MeHg ranged from 3.6 to 7.83 ng/L, considerably higher than during the rest of the year, when MeHg was 0.72 to 2.40 ng/L at this location. This pattern supports the hypothesis that methylation occurs in the river (and possibly the reservoir) in mid to late summer, when temperatures reach high values and DO declines to low values.

1.3.3 Biota

In fish samples from the Carson River system, there is a clear pattern of higher Hg levels near and downstream from Dayton than upstream. Upstream from Dayton and the mill-sites, in 30 samples collected between 2005 and 2008 from the East Carson River and the main-stem Carson River near and upstream from Carson City, average Hg results for tissue samples from various species of fish ranged from 0.04 to 0.47 parts per million (ppm; equivalent to mg/kg) (unpublished Nevada Department of Environmental Protection [NDEP] data). Near and downstream from Dayton, individual fish samples ranged from 0.33 to 11.27 ppm Hg for a wide variety of fish (average values were not always available); predators such as bass and walleye consistently had the highest concentrations (unpublished NDEP data for 2005-2008; Cooper et al., 1985). In the downstream portion near the reservoir, fish from near Fort Churchill tended to have the highest levels, as 88% (28 of 32) of the fish sampled by Cooper et al. (1985) had Hg concentrations greater than the U.S. Food and Drug Administration (FDA) action level of 1 ppm, while none of their samples from Dayton or farther-upstream locations had levels above 1 ppm. More-recent sampling has shown the same general geographic pattern of higher downstream contamination, although values greater than 1 ppm also have been reported from some upstream areas, including Dayton.

1.4 TRANSFORMATION AND TRANSPORT MECHANISMS

A detailed evaluation of the factors that influence the fate and transport of Hg and MeHg will be presented in the RI report. As the greatest concern is for accumulation in piscivorous (fish-eating) fish and birds, the form of Hg of greatest interest is MeHg, which is biologically active and bioaccumulative. Among other factors, seasonally elevated temperatures as well as reducing conditions along portions of the river are likely to contribute to increased methylation of Hg.

As summarized in the previous section, Hg and MeHg are both present in the river, bank sediments, and floodplain at elevated levels in both dissolved and particulate forms. For both these chemicals, especially Hg, partition coefficients strongly favor sorption of dissolved components to the solid phase (Rytuba, 2000); nevertheless, Hg and MeHg are of concern even at parts-per-trillion (nanograms per liter) levels in surface water, and the presence of Hg at ppm levels in the solid phase along the entire length of the river below Dayton creates potential concern for the release of Hg in surface waters in those portions of the watershed.

The initial releases of mercury to the environment were at the Comstock-era (1860-1890) mills, largely as solid particles of Hg-silver-gold amalgam, in which the Hg is fairly tightly bound. Some release of mercury from amalgam grains occurs due to oxidation of Hg(0) to Hg(II). Hg(II) generally is considered the reactive form of Hg that can be transformed to MeHg, although there is evidence that the aqueous dissolved HgS(0) complex is a primary precursor of MeHg (Benoit et al., 1999). After Hg(II) is formed, it is commonly further transformed, such as by sorption to solid particles of clay or organic matter, generating a relatively stable form in which Hg can be transported downstream with particulate matter.

The geomorphology of the Carson River below the mills near Dayton includes meanders in which sediments have been deposited on the insides of the meanders and eroded from the outsides of the meanders, as well as overbank deposits that have been laid down during high-discharge flooding events (see, e.g., Miller et al., 1999). Channel migration through the years has caused deposition of Hg along the length of the floodplain, and for distances up to several hundred yards from the current active river channel. While Hg is transported in the river and deposited in the reservoir in both suspended and dissolved forms in typical yearly cycles according to seasonal patterns, the irregular high-discharge flooding events can be responsible for transporting and depositing very large volumes of Hg. For example, the January 1997 flood was estimated to have a peak flow of 22,300 cfs, and resulted in the transport of 3,000 pounds of Hg down-valley to the reservoir in a single day (January 3), and 10,000 pounds from January to September 1997; about 80% of this Hg was retained by the reservoir (Hoffman and Taylor, 1998).

Hg and MeHg are present in the solid phase in sediments in the floodplain and river channel at levels significantly above background. In the case of Hg, concentrations in sediments at and below the mills increase by two to three orders of magnitude relative to concentrations upstream; the increase in MeHg concentrations in sediments is less pronounced, at less than an order of magnitude. Similarly, beginning near the mills around Dayton, the water concentrations of unfiltered total Hg increase sharply downstream, by two to three orders of magnitude. Again, however, the increase of unfiltered MeHg in water is about one order of magnitude. Filtered total Hg and filtered MeHg both increase downstream by roughly an order of magnitude. Interestingly, Hg levels in biota also increase by roughly an order of magnitude from upstream to downstream portions of the river. The increases in unfiltered MeHg and in dissolved forms of Hg, while more modest than for unfiltered total Hg, appear to be more than enough to account for the elevated Hg levels in fish, birds, and other biota, as Hg levels in fish from the Carson River and Lahontan Reservoir are some of the highest known worldwide.

Several studies have evaluated the processes and rates of Hg methylation and demethylation in the Carson River system. Based on the detection of elevated levels of MeHg (up to 23 ug/kg) in some upper Carson riverbank sediments (Bonzongo et al., 1996a; CH2M Hill, 2008), it appears that some methylation occurs in the solid phase, possibly in wet sediments or soils. However, most studies at the Carson River and elsewhere have focused on methylation in submerged sediments. Marvin-Dipasquale et al. (2001) have reported relatively high rates of methylation in downstream portions of the upper Carson River, specifically near Fort Churchill, a few miles above Lahontan Reservoir. However, a number of variables influence the net amount of Hg methylation: the process is fostered by: elevated concentrations of ionic Hg (Hg[II], a form of Hg susceptible to methylation), sulfate reduction, low concentrations of reactive sulfides but the presence of neutral dissolved sulfide complexes, iron and manganese reduction, increased temperature, elevated concentrations of dissolved organic carbon, a low rate of MeHg degradation, and a shallow subsurface depth at which methylation occurs (after formation, MeHg can be degraded during upward migration through near-surface oxic zones of shallow sediments). In general, MeHg degradation proceeds at a higher rate than Hg methylation, resulting in a limited buildup of MeHg, but also resulting in relatively rapid cycling of Hg from non-methylated to methylated forms and back. The above-listed factors have resulted in dissolved MeHg occurring typically at a level of up to several percent (commonly 0.5 to 5%) of the level of dissolved Hg in many upper Carson River water samples (USGS sampling program, unpublished data). This proportion of MeHg to Hg is fairly common at sites evaluated for Hg. However, for some samples collected during the active methylation period that occurs during some late-summer seasons, dissolved MeHg can be as high as 10 or 20% of dissolved total Hg.

1.5 POTENTIAL EXPOSURE PATHWAYS TO POTENTIAL RECEPTORS

Figure 1 is a schematic illustration of the exposure pathway evaluation for the upper Carson River. Despite the comprehensive warning from the State of Nevada, residents and recreational users could be exposed to COPCs by ingestion of contaminated tissue of fish that have bioaccumulated residues of MeHg (which constitutes most of the total Hg present in fish tissue). As illustrated on this figure, potential receptors also could be exposed to Hg contamination in surface waters, soils, and sediments via incidental ingestion, dermal contact, and inhalation of soil particulates, such as when water levels decline after seasonal highs in the spring and early summer.

Aquatic receptors (e.g., invertebrates, fish, frogs, and waterfowl) could be exposed to Hg or MeHg via ingestion and skin contact. Potential exposures of terrestrial and aquatic plants could occur through uptake of chemicals from soil, sediment, and surface water. If evidence of bioaccumulation is observed, then it is possible that bioaccumulation via terrestrial herbaceous vegetation, such as grasses or irrigated crops, could become a viable human or ecological pathway. In general, Hg bio-uptake into plants is expected to be much lower than bio-uptake into animal tissue. Based on prior sampling conducted by various investigators, Hg concentrations in piscivorous and other fish in the upper Carson River often have been well above the FDA action level for Hg (1 ppm) and the EPA consumption advisory limit of 0.3 ppm, with concentrations in fish in the lower part of the river (near the reservoir) ranging up to 11 ppm.

2.0 LAHONTAN RESERVOIR (OU2B)

This CSM for the Lahontan Reservoir portion of the Carson River Mercury Site (OU2B) summarizes the sources, release and transport mechanisms, pathways, and ultimate receptors that are affected by Hg and MeHg in the reservoir environment. As for the upper Carson River CSM segment presented above, particular interest at the Lahontan is the transport of Hg via sediment and surface water, and the effects of the broad dispersion of Hg on biota. Comprehensive discussions of the nature and extent of contamination, and of contaminant fate and transport, will be presented in the RI report. This CSM is intended to convey the major themes of Hg distribution, transport, and environmental fate, to support decisions about overall project direction (such as the steps that may need to be taken to close any possible data gaps) and to assist in the preliminary screening of remedial alternatives for OU2. The CSM also identifies the routes by which human and ecological receptors at the site could come into contact with chemicals present in different environmental media.

2.1 ENVIRONMENTAL SETTING AND LAND USE

The Lahontan Reservoir shoreline is characterized by land used primarily for rangeland and recreational activities. The land immediately surrounding Lahontan Reservoir is largely State of Nevada and U.S. Bureau of Reclamation property, with the Lahontan State Recreation Area occupying much of the Middle and Lower (northern) Basin shorelines. It is not likely that significant development would take place along the immediate shoreline owing to seasonally fluctuating water levels typical of the reservoir (generally 30 feet or more each year). The shoreline can fluctuate laterally by as much as a mile owing to seasonal fluctuations in water levels. Camping, boating, water skiing, and canoeing are typical activities of visitors to Lahontan State Recreation Area, which at 116,000 visitor-days is the third most-visited state park in Nevada. There are boat-launching facilities at other locations along the reservoir shoreline as well, and fishing is a common activity across the reservoir. The reservoir supports a year-round warm-water fishery of white bass, walleye, white crappie, catfish, and brown and rainbow trout. As noted for the upper Carson River below Dayton, the Nevada State Health Division has issued a health advisory recommending that no fish caught from the Lahontan Reservoir should be consumed (http://www.ndow.org/fish/health/, accessed August 25, 2011). However, despite the health advisory, human exposures to Hg may occur due to consumption of fish from the reservoir.

As noted for the upper Carson segment of the CSM, flow in the river portion above Lahontan Reservoir is highly seasonal, with peaks in the spring of each year due to snowmelt in the mountains. Based on flows at Fort Churchill, about eight miles above the reservoir, monthly flows to the reservoir during the spring snowmelt season (April through June) average 543 to 1,101 cubic feet per second (cfs). Flow to the reservoir then declines rapidly to very low values from August through October (ranging from 1 to 38 cfs), and flow then increases slightly through the fall and winter months (November through March). However, isolated and irregular events of extremely high flows in the river can occur due to rain-on-snow storms during the winter months, when heavy precipitation is augmented by snowmelt, such as on January 3-4, 1997, when a record flow of 22,300 cfs was recorded at Fort Churchill. In addition to inflows from Carson River, the Truckee Canal has provided up to 40% of the annual flows to the Lahontan Reservoir at a point not far from the northern terminus of the dam, although these flows have declined in recent years due to a mandate that increased flows be reserved for Pyramid Lake.

The Lahontan Reservoir is managed to provide irrigation water for approximately 57,000 acres in the Newlands Irrigation District around Fallon. As a result, average flows to the irrigated areas have been maintained at fairly consistent levels throughout the growing season (from April through September), with monthly averages for this period ranging from 624 to 940 cfs at the USGS "Below-Lahontan" station. The average depth of the reservoir is 16 feet in the Upper (southern) Basin, and 36 feet in the downstream portion occupied by the Lower (northern) Basin; maximum depth is 85 feet, in the Lower Basin. In 1982, the USGS estimated that an average of about 0.8 inches of sediment per year are deposited in the Lower Basin behind the dam. Another noteworthy feature is that there are two sizeable overflow basins located adjacent to the Lower and Middle basins of the reservoir; these basins are normally dry, but may receive water during high-flow years, with possible impacts on water quality and Hg methylation.

Due to the extreme variation in inflow volumes, continuous outflow during the growing season, and extensive evaporation during the summer, the water level in Lahontan Reservoir varies significantly across the span of a single year. The average annual high-stand of water from 1917 to 1970 was about 4,160 feet above sea level, and the average low-stand was about 4,135 feet, while the highest and lowest levels on record have been 4,164 and 4,070 feet, respectively (Katzer, 1971).

Cooper et al. (1983) observed stratification of the reservoir in two consecutive summers (1980 and 1981), with the thermocline at approximately 35 feet depth during the higher-water year (1980), when stratification was most pronounced. The lower zone (hypolimnion) developed low DO levels that created nearly anaerobic conditions throughout most of its depth extent, and anoxic conditions prevailed at the sediment-water interface. They also reported that DO reached relatively low levels even in areas that were not stratified during the summer. These observations are of significance because of the propensity for methylation of Hg to occur in bottom sediments under anoxic conditions.

2.2 CHEMICALS OF POTENTIAL CONCERN

The primary COPC for all media is Hg, including its MeHg form. Elevated concentrations of Hg and MeHg have resulted in the ongoing comprehensive state health advisory against consumption of any fish caught in the Lahontan Reservoir.

2.3 SOURCES OF RELEASE

The mills along the Carson River and its tributaries have been identified as the primary sources of Hg contamination in the watershed. As noted for the upper Carson CSM segment, Hg-contaminated material has been redistributed downstream through the years, during annual spring snowmelt and during high-discharge flooding events capable of eroding alluvial fan or bank sediments. Considerable amounts of Hg have reached Lahontan Reservoir. Hg contamination of sediment, surface water, and biota are briefly summarized below.

2.3.1 Sediments

In general, total Hg concentrations in upper Carson River channel and floodplain sediments are in the range of 1 to 25 mg/kg along the stretch of the river from the former Empire mill to the Carson delta, where the river empties into the reservoir, with locally higher concentrations in some bank sediments. While portions of OU1-area soils near the mills in the Dayton area were remediated in the late 1990s, Hg-contaminated sediments are very widely distributed along the entire extent of the upper Carson River at and below the mills (a reach of approximately 40 miles); as a result, it is presumed that these Hg-containing sediments will be a continuing source of Hg to the reservoir.

In addition to the river acting as a source for solid-phase and dissolved Hg to the reservoir through the ongoing transport of contaminated sediment, existing reservoir sediments are known to contain Hg at levels of potential concern. Cooper et al. (1985) collected samples along nine transects crossing Lahontan Reservoir along most of its length. Total Hg concentrations in composited samples for the nine transects ranged from 2.8 to 30.5 mg/kg, with the average being 15.0 mg/kg. The highest level was from the Lower Basin, about one mile from the dam. The lowest concentration was in the transect across the lower Narrows, the narrowest part of the reservoir, where deposits are predominantly sandy.

In a more detailed study, Miller et al. (1995) identified highly variable total Hg levels according to sediment type: average total Hg values in their eight identified stratigraphic units varied from 0.06 to 23.74 ppm. The highest values were found in the “delta complex” and “bottom floodplain” units, at 20.05 and 23.74 ppm Hg, respectively, while the other six units all had average values less than 3 ppm Hg. Hg was correlated with proportion of fines (silt + clay) and with organic matter. Hg also was commonly considerably higher at depth within the sediments, with concentrations in some bottom floodplain sediments near the dam at 50-260 ppm; these intervals were surmised to have been deposited shortly after the dam was completed in 1915. The depth variation was not always present in areas that have been exposed, due to vertical mixing processes upon drying, shrinking, mud crack formation and filling with low-Hg sands, followed by swelling of the sediment; multiple generations of filled mud cracks were noted, likely accounting for thorough mixing of Hg levels in periodically exposed sediments.

Limited sampling for several other studies has yielded generally similar, though variable, total Hg concentrations in sediments: Van Denburgh (1973) reported values of 12 and 20 mg/kg Hg for the Upper Basin and 5.3 mg/kg in the Lower Basin, while Wayne et al. (1996) reported values ranging from 3.2 to 10.5 mg/kg Hg for the Upper Basin and 0.01 to 60 mg/kg Hg for the Lower Basin. Gustin et al. (1994) also reported widely ranging values from the reservoir, from

0.02 to 103 mg/kg Hg. The lower values in these ranges apparently reflect pre-mining sediments.

2.3.2 Surface Water

To supplement the limited scope of water-quality data for Lahontan Reservoir, it is helpful to consider the Hg concentrations in the waters flowing into Lahontan Reservoir. As noted in the upper Carson River CSM segment above, water at Weeks Bridge, several miles above the reservoir, has averaged 2,550 and 27.8 ng/L for unfiltered and filtered total Hg, respectively, while MeHg concentrations in unfiltered and filtered river waters have averaged 2.96 and 1.20 ng/L, respectively. However, these values have been extremely variable across the seasons of a single year, and are related most directly to levels of suspended solids and river flow volumes. The Truckee River, which has supplied up to 40% of the flow to the reservoir via the Truckee Canal at its entry into the Lower Basin of the reservoir, has waters with unfiltered total Hg values of approximately 4 ng/L (Wayne et al., 1996); as a result, the effect of the Truckee Canal water is to dilute the higher Hg levels arriving at the reservoir from the upper Carson River.

The water sampling record for the reservoir proper is quite limited, with only two to four samples collected in each of the Upper and Lower basins in three different studies in the 1990s (Gustin et al., 1994; Bonzongo et al., 1996; Wayne et al., 1996), along with USGS sampling at one Upper Basin location in 1998-1999 (unpublished). Seasonal variation was apparent in these studies, with values for Hg and MeHg generally higher in springtime in the first three studies; also, the samples fell close to the lower end of the range reported for the nearby USGS Weeks Bridge samples for the corresponding months. There was also spatial variation in the reservoir, as the concentrations of Hg and MeHg in the Lower Basin were lower than those in the Upper Basin by factors of three to 12. Lower Hg and MeHg in the Lower Basin is also consistent with the results from sampling at the USGS "Below-Lahontan" station, which had roughly similar results for Hg and MeHg in corresponding months. Considering these data together, it appears that there is a loss of a major fraction of Hg and MeHg from the surface water along the length of Lahontan Reservoir.

As mentioned in the upper Carson River CSM segment, the USGS conducted sampling from April 1998 to February 1999 at five locations in the upper Carson River and one location in the Upper Basin of Lahontan Reservoir, about two miles downstream from where the river empties into the reservoir. The Upper Basin location showed MeHg levels higher than those in the Carson River for nearly all sampling dates, with peak values ranging from 3.6 to 7.83 ng/L in summer 1998. This period coincided with elevated water temperatures (>20 °C), and low levels of DO (<4 mg/L) (see Figure 3). The pattern is also consistent with other findings of increased methylation in the river and parts of the reservoir in the summer.

There is other evidence for methylation of Hg in late summer, approximately coinciding with likely periods of stratification of the reservoir. This hypothesis is based on the elevated MeHg levels reported for the Below-Lahontan station in late summer of 2005 and 2006, when unfiltered MeHg ranged up to 13.8 and 35.2 ng/L, respectively; in both cases, the concentrations were much higher than those observed upstream from the reservoir at Weeks Bridge, where MeHg was no higher than 2.5 ng/L in the same period. In other years, MeHg below the reservoir generally has peaked in the late summer at 0.5 to 3 ng/L, while values in the rest of the year are mostly 0.1 to 0.5 ng/L. While MeHg has often shown late-summer peaks in the upper Carson River, the 2005 and 2006 peaks below the reservoir, though apparently not an annual occurrence, indicate that in-reservoir methylation can be quite significant volumetrically in some years. (2005 and 2006 were the highest-water years for the reservoir since 1998; all three years had high MeHg levels in the reservoir, based on results for the Below-Lahontan station.) Cooper et al. (1983) had demonstrated that reservoir stratification occurred at about 35 feet in 1980 and 1981, and was significant enough to cause DO to decline in the hypolimnion to levels of 0.05 to 0.50 mg/L, respectively. Sulfate-reducing conditions in near-surface bottom sediments (top 20 centimeters or so) are widely documented at other sites to foster the methylation of Hg. Upon mixing of hypolimnic and epilimnic waters after stratification broke down in the early fall, clear impacts on the entire reservoir could be seen, as DO and pH values in shallow waters shifted toward values typical of the hypolimnion. Low-DO conditions in the hypolimnion could produce the sulfate-reducing conditions typically needed to enhance methylation in shallow bottom sediments, and this appears to occur in certain years, perhaps due to higher-than-normal inflows from the river, as in 2005 and 2006.

2.3.3 Biota

Richens and Risser (1975) collected 24 fish of four species from Lahontan Reservoir in 1972 and reported mean values for tissue from each species ranging from 0.374 to 1.297 ppm. Cooper et al. (1985) collected 107 fish of 13 species from Lahontan Reservoir in 1983-1984 and reported mean values for each species ranging from 0.56 to 1.80 ppm. The State of Nevada Department of Wildlife and U.S Bureau of Reclamation collected 177 fish of three forage (non-piscivorous) species over the period of 1981-1996 and reported species-mean values ranging from 0.94 to 1.48 ppm; for 297 piscivorous (fish-eating) fish of 14 varieties they reported species-mean values of 0.56 to 4.81 ppm (Craft et al., 2005). For 2005-2007, unpublished annual results from the State of Nevada reported collection of 41 fish of 12 varieties with means ranging from 0.93 to 3.57 ppm. In 2010, unpublished results from the State of Nevada reported mean values for five varieties of 22 fish ranging from 0.73 to 8.69 ppm. The abnormally high mean value in 2010 was for five large walleyes (each about 2 kg).

As is typical, Hg in fish at Lahontan correlated with fish size as well as with trophic status; high results for some carp and catfish, both omnivores, may be a result of the larger sizes of some specimens. Other than year-to-year fluctuations, it does not appear that fish Hg values have fluctuated significantly from at least 1983 to the present. In general, piscivorous fish have had Hg levels considerably higher than those reported for forage fish, and the vast majority of piscivorous fish in the reservoir have exceeded the FDA action limit of 1 ppm. Fish collected within Lahontan Reservoir generally have had some of the highest Hg values for fish in the Carson River system, although fish from the river at Fort Churchill (eight miles above the reservoir) and from just below the Sagouspe Reservoir (below the Lahontan) (Cooper et al., 1985) have also been at similar levels.

Among other biota, one study (Henny et al., 2002) of Hg in piscivorous birds nesting at Lahontan Reservoir and in the downstream Carson Lake area reported higher degrees of bioaccumulation at Lahontan than downstream. Hg concentrations in diet (food in stomachs) were 0.17 to 1.96 mg/kg, largely above the 0.4 mg/kg effect-levels for these birds as delineated by Heinz (1979); the livers of black-crowned night herons, snowy egrets, and double-crested cormorants ranged from 5.01 to 222 mg/kg, all above effect-levels of 4.3 mg/kg (Heinz, 1979).

Subsequently, Henny et al. (2007) reported on a 10-year study of the eggs and the blood of juvenile and adult herons and egrets nesting along the reservoir, and determined that most eggs were below the effect level of 0.8 mg/kg; however, the blood of more than half of the juvenile herons and egrets sampled were above an informal effect level of 2.0 mg/kg. The researchers correlated blood-Hg levels of these birds with unfiltered MeHg concentrations in water below the reservoir.

2.4 TRANSFORMATION AND TRANSPORT MECHANISMS

A detailed discussion on the factors that influence the transformation, fate, and transport of Hg and MeHg will be presented in the RI report. The form of Hg of most interest is MeHg, which is biologically active and bioaccumulative, with the greatest concern being its accumulation in piscivorous fish and birds. Based on the detection of elevated levels of MeHg (up to 23 ug/kg) in some upper Carson River sediments (Bonzongo et al., 1996; CH2M Hill, 2008), it appears that some methylation occurs in the solid phase, possibly in wet sediments or soils; such MeHg may be transported to the reservoir in a form sorbed to suspended matter. As discussed above in the upper Carson River CSM segment, while methylation apparently peaks in the river in late summer, it appears that it also can occur in the reservoir at this time of year, both in the relatively shallow waters of the upper and middle basins, and in deeper waters during years when an anoxic hypolimnion develops as a result of stratification.

While there is not an ongoing sampling program for a station in Lahontan Reservoir, stations a couple miles above (Weeks Bridge) and just below the reservoir (Below-Lahontan) have been sampled since late 1997. In 10 of 13 late-summer seasons with a sampling record, there has been a late-summer peak in MeHg at the Below-Lahontan station, and in two of these years the MeHg results, which ranged up to 13.8 and 35.2 ng/L, were considerably higher than those reported for the Weeks Bridge samples (2.15 ng/L or less). The likelihood of methylation occurring at depth in the reservoir in late summer of 2005 and 2006 appears fairly high, as the Below-Lahontan samples had distinctly lower DO at this time: DO in these samples was near 4 mg/L, compared to typical values throughout the year of 7 to 12 mg/L. The nadir of DO appears to be significant because of the fact that this location is outside the reservoir, yet still reflects apparent reducing (and possibly anoxic) conditions within the reservoir. The idea of a late-summer anoxic hypolimnion is supported by the limnologic evaluation by Cooper et al. (1983), in which they reported that post-stratification mixing in 1981 and 1982 showed reservoir-wide depletions in DO and pH that they attributed to late-summer stratification and reducing, locally anoxic conditions.

In the 11 of the last 13 years when late-summer values of MeHg at the Below-Lahontan station were lower than those for Weeks Bridge, it may be that there was little net methylation occurring within the reservoir. Methylation in those years may have been limited primarily to the upper Carson River between Dayton and the reservoir, and shallow portions of the reservoir in the upper and middle basins.

The long-term USGS monitoring program provides a good database indicating the overall Hg and MeHg storage (or production) in the Lahontan Reservoir. At the Weeks Bridge station, several miles above the reservoir, unfiltered total Hg has averaged 2,550 ng/L from October 1997 to May 2011; at the Below-Lahontan station during this period, unfiltered total Hg has been less than 10% of this value, averaging only 249 ng/L. MeHg shows a similar decline, though not nearly as steep: at the Weeks Bridge station, unfiltered MeHg has averaged 2.96 ng/L, while at the Below-Lahontan station, it has averaged 1.14 ng/L, some 60% lower. (Filtered values show a similar pattern, though the declines are not as abrupt as for the unfiltered species.) Thus it appears that, on a long-term basis in recent years, the reservoir has retained 90% of the total Hg and 60% of the MeHg that has been supplied to it. However, the lower value for retention of MeHg may reflect some Hg methylation occurring within the reservoir with subsequent dissolved-phase transport below the dam (or uptaken in planktonic algae), as well as the fact that MeHg tends to be present in the dissolved state at a higher proportion (about 30%) than does total Hg (about 1%), and is likely somewhat more mobile than total Hg.

While Hg is transported in the river and deposited in the reservoir in both suspended and dissolved forms in yearly cycles according to seasonal patterns, the irregular high-discharge flooding events can be responsible for transporting and depositing a very large volume of Hg in the reservoir. For example, the January 1997 flood was estimated to have a peak flow of 22,300 cfs and resulted in the delivery of 3,000 pounds of Hg to the reservoir in a single day, while about 10,000 pounds of Hg was transported to the reservoir from January to September 1997 (7,000 pounds of which was in January); about 80% of this Hg was retained by the reservoir (Hoffman and Taylor, 1998).

Lahontan Reservoir is a large body of relatively quiescent water that may be a significant site of Hg methylation in the summer in both the shallow waters of the upper and middle basins (based on data from one reservoir location in 1998) and in the deeper waters of the Lower Basin when stratification occurs and anoxic conditions develop in the hypolimnion (based on ongoing monitoring above and below the reservoir). The frequency and duration of methylation in the reservoir is of interest for impacts to biota both within the reservoir and in the river and wetlands below the reservoir, and should be further evaluated.

Methylation/demethylation ratios have been estimated at values ranging from 0.06 to 0.26, as demethylation is generally more rapid than methylation (see, e.g., Marvin-DiPasquale et al., 2001). However, these ratios may differ significantly across the reservoir based on varied sediment types, water depths, and chemical conditions (which also change with the season), such as increased rates of methylation during periods of reservoir stratification. Marvin-DiPasquale et al. (2001) evaluated methylation in sediments collected from selected locations along the river system, from the upper Carson River near Dayton to Lahontan Reservoir to the agricultural drains and wetlands downstream from the reservoir. They concluded that the delta region in the upper portion of the reservoir had high rates of MeHg production, while low production rates prevailed in the downstream portion of the reservoir (methylation was also proceeding at high rates at Fort Churchill, in a downstream portion of the upper Carson, and in the agricultural drains in the Carson Desert). However, Marvin-DiPasquale et al. (2001) did not collect samples from deep portions of the reservoir that would have been part of the anoxic hypolimnion, which is known to have formed during the late summer of certain years (Cooper et al., 1983), and which may have provided conditions amenable to Hg methylation.

Kuwabara et al. (2002) studied benthic flux, or transport of dissolved chemical species between the Lahontan Reservoir's water column and the underlying sediment. Benthic flux varies over multiple temporal and spatial scales, and is affected by biological (e.g., bioturbation that enhances advection across the benthic surface) as well as chemical and physical factors. For MeHg, the fluxes measured for two dates were positive at two of three sites, indicating upward transport of MeHg from the sediment into the bottom water; the two positive fluxes were of a much higher magnitude than the negative flux measured for the third site.

In their model of the fate of Hg and MeHg in the reservoir, Gandhi et al. (2007) modeled incoming MeHg at approximately 0.2% (4 grams per day [g/d]) of the total Hg entering the reservoir from the river, while one-eighth of this amount of MeHg leaves the reservoir at the dam. Their net diffusive flux of MeHg from the sediments, however (26 g/d), was much larger than measured fluxes. They considered that significant sorption by iron and manganese oxides near the sediment surface reduced MeHg flux from the sediment to 1.6 g/d. A major proportion (60%) of the MeHg flux (2.3 g/d) is taken up by fish, of which 0.2 g/d is lost through fishing; the net burial of MeHg was modeled to be 1.5 g/d. Thus they and several other investigators have assessed the reservoir to be a net sink of MeHg. However, as they point out, a critical component of the fate of MeHg rests upon two parameters that are not well constrained, specifically sorption by bottom sediment (discussed above), and the methylation/demethylation rate.

The proportion of Hg that is MeHg in the Lahontan area is generally low, being commonly in the range of 0.1–0.5% for unfiltered water samples. In sediments of the Carson River system overall, MeHg appears to be an even lower percentage of total Hg (0.01–0.1%). These proportions are much lower than reported for other contaminated areas and for uncontaminated Carson-area samples. The relatively low methylation efficiency in the Carson-Lahontan system may reflect a number of factors, such as the relatively alkaline waters in the river and especially in the reservoir; an inhibitory effect on microbial activity due to toxic effects from high Hg levels; relatively unreactive Hg mineralogy (Hg-silver-gold amalgam) that leads to low Hg availability; inhibition of Hg uptake due to elevated selenium; and low amounts of dissolved organic carbon. It is interesting that the late summer is the one season when MeHg levels in water can be a major fraction (up to 35%) of total Hg levels; this time is marked by pH values in bottom waters that are slightly acidic (pH~6.7; Cooper et al., 1983), much lower than in surface waters (pH~8.8).

Certain aspects of Lahontan Reservoir may be partly explained by biological nutrient levels. Cooper et al. (1983) and NDEP (2007) have observed that the reservoir is nitrogen-limited, based on correlations of nitrogen to chlorophyll, and ratios of total nitrogen to total phosphorous (TN:TP) of less than 4; values less than 10 are generally considered nitrogen-limited. The reservoir has remained nitrogen-limited despite the nutrient limitations, especially regarding phosphorous, that have been implemented since 1987 (NDEP, 2007). The low amounts of nitrate may be one factor that facilitates MeHg production, in that it makes sulfate reduction a more prevalent process in organic matter mineralization. Nitrate reduction is more energetically favorable than sulfate reduction, and thus precedes it in the sequence of mineralization processes. As pointed out by Todorova et al. (2009), nitrate has not been found to be associated with Hg methylation; they hypothesize that nitrate reduction can delay the onset of sulfate reduction, and thus delay the Hg methylation that generally requires sulfate-reducing conditions, based on observations of the hypolimnion at Onondaga Lake, New York, another nitrate-poor lake. Nitrate amendments are being considered at this location as a remedial option to control Hg methylation. It is also interesting to note that blooms of toxin-producing blue-green algae, one of the top water-quality concerns for Lahontan Reservoir, tend to be limited to periods when nitrate has been depleted in the reservoir in late summer.

Several important questions about Hg transformation and transport processes in the reservoir have not been fully investigated and remain to be answered. Perhaps one of the most important is the frequency and the degree to which stratification-related anoxic events occur; such events occurred in 1980 and 1981, but Hg data are not available for that time. In August and September of 2005 and 2006, sharply higher MeHg values downstream from the reservoir, coupled with low DO, suggest that active methylation in reservoir bottom waters or sediments may have occurred at least on those occasions, possibly due to anoxic conditions that developed during reservoir stratification.

Another question of interest is the effect of the two overflow basins located near the Upper and Middle basins. It is possible that flooding of these areas could either re-suspend previously deposited sediments with elevated levels of Hg, or could result in a pulse of methylation activity, as has been reported by others for newly-flooded reservoirs. However, it is possible that methylation may be unlikely if the overflow basins have low proportions of organic carbon; the methylation reported from other locations tends to be based on the presence of easily oxidized organic matter. Nevertheless, occasional flooding of these overflow basins is likely to occur in the future, and the impact of such flooding on both the transport and methylation of Hg should be investigated.

As noted above, MeHg generally tends to be lower in water exiting the reservoir than in the river immediately upstream from the reservoir. The fate of MeHg in the reservoir is likely to involve one or more of a variety of processes, including consumption by biota; removal from the reservoir of biotic MeHg by human or avian consumption; deposition of MeHg in detrital organic matter; transformation to Hg by demethylation; burial of MeHg and Hg to depths below the active zone of methylation and demethylation. The last of these processes would constitute effective removal from the system.

Burial of Hg and MeHg is of particular interest, because after burial below a certain threshold, bottom sediment may no longer be accessible to methylation or re-suspension. As noted by Jernelov (1971), only 2-9 cm of low-Hg sediment above Hg-contaminated sediment are needed to protect against MeHg production in bottom sediments. Methylation appears to be limited to a narrow zone near the sediment surface, where sulfate reduction is active. It is likely that some of the sediments containing extremely high Hg concentrations, presumed to have been deposited fairly soon after completion of the dam (Miller et al., 1995), may now be effectively buried to the extent that they are below the typical methylation zone, and are also unlikely to be re-suspended during future low-stands of the reservoir. Burial of Hg and MeHg may not permanently sequester these contaminants in the upper and middle basins, as these areas can be subject to erosion during subsequent reservoir low-stands, when the sediments are either exposed subaerially or are subject to wave action. However, the relatively rapid sedimentation in the Lower Basin (about 0.8 inches, or 2 cm, per year) along with the fact that greater water depth in this basin makes erosion of the sediment much less likely, combine to make burial and effectively permanent removal of Hg and MeHg a likely fate for some of the Hg and MeHg that enter the reservoir.

2.5 POTENTIAL EXPOSURE PATHWAYS TO POTENTIAL RECEPTORS

Figure 2 is a schematic illustration of the exposure pathway evaluation for the Lahontan Reservoir. Residents and recreational users could be exposed to COPCs by ingestion of contaminated tissue of fish that have bioaccumulated residues of MeHg and total Hg. Potential exposures of terrestrial and aquatic plants could occur through uptake of chemicals from soil, sediment, and surface water; however, vegetation along reservoir shorelines is quite sparse, and farm fields are not apparent (the irrigated fields are at least three miles below the reservoir). As a result, Hg uptake into plants is not considered to be a significant pathway for the reservoir. Potential exposures from soils and sediments via incidental ingestion, dermal contact, and inhalation of particulates are possible, such as when water levels are drawn down after the early summer peak influx from the river and sediments become exposed. Burial is a fate-and-transport process that likely reduces the amount of Hg and MeHg in the active methylation-demethylation cycle, as the latter processes are limited to shallow sediment and the water column. Consequently, although burial is not an exposure process, it is included in Figure 2.

Aquatic receptors (e.g., invertebrates, fish, frogs, and waterfowl) could be exposed to Hg and MeHg via ingestion and skin contact. Based on a long record of sampling conducted by various investigators, Hg concentrations in piscivorous and some other fish generally have been well above the U.S. FDA action level for Hg of 1 ppm, ranging up to 16 ppm, while the blood of piscivorous birds in the area of the reservoir has commonly exceeded 2 ppm.

3.0 LOWER CARSON RIVER (OU 2C)

The CSM for the lower Carson River portion of the Carson River Mercury Site summarizes the sources, release and transport mechanisms, pathways, and ultimate receptors that are affected by Hg and MeHg. The lower Carson River portion encompasses that portion of the Carson River downstream from Lahontan Reservoir and upstream from the Lahontan Valley wetlands. As for the upper Carson River and Lahontan Reservoir CSM segments presented above, particular interest in the lower Carson River segment is the transport of Hg via sediment and surface water, and the effects of the broad dispersion of Hg on biota. Comprehensive discussions of the nature and extent of contamination, and of contaminant fate and transport, will be presented in the RI report. This CSM is intended to convey the major themes of Hg distribution, transport, and environmental fate, to support decisions about overall project direction (e.g., steps that may need to be taken to close any possible data gaps) and to assist with the preliminary screening of remedial alternatives for OU 2. The CSM also identifies how human and ecological receptors at the site could come into contact with chemicals present in different environmental media.

3.1 ENVIRONMENTAL SETTING AND LAND USE

The lower Carson River watershed is characterized by land used primarily for agriculture based on irrigation water provided as part of the Newlands Irrigation Project. Areas near the wildlife refuges and wildlife management areas are used for recreational purposes and as natural areas (albeit modified by human manipulation of surface-water hydrology). The river enters the lower Carson segment from Lahontan Reservoir, and most of its flow is diverted at the Carson Diversion Dam, located about three miles downstream from the Lahontan Dam, to flow generally northeasterly through a variety of irrigation canals. Flows at USGS stations on the lower Carson River below the diversion indicate that, below Fallon, the flow in the river itself is only about 1% of the flow that leaves the reservoir. Irrigation drainage water is collected in drains that tend to have more-saline water than the applied water; irrigation drainage is then conducted to a sequence of lakes that in turn deposit water in the Carson Sink, an enclosed depression. Average annual precipitation in this part of the drainage basin is approximately 4 to 5 inches. Flow in the irrigation canals is highly seasonal and is geared to the growing season of April through November.

The river is accessible for recreational activities, and most of lower Carson River is contained within the area considered to host a warm-water fishery. There are localized areas where fishing occurs in the lower Carson River, such as the river below the Carson Diversion Dam, and the Sheckler Reservoir. The Nevada State Health Division health advisory against consumption of any fish caught from the Carson River applies to the river from Dayton downstream to and including the Lahontan Reservoir (http://www.ndow.org/fish/health/, accessed August 25, 2011); below the reservoir, however, there is only a limitation on fish caught from the Indian Lakes area, which is considered part of the Lahontan Valley wetlands (OU 2D). As fishing occurs in the lower Carson River area, human exposures to Hg may occur due to consumption of fish along this stretch of the river.

3.2 CHEMICALS OF POTENTIAL CONCERN

The primary COPC for all media is Hg, especially its methylated form. Elevated concentrations of Hg and MeHg have resulted in the state health advisory noted above, cautioning against consumption of any fish caught in the Carson River from Dayton to and including the Lahontan Reservoir (OU 2A and 2B), and for numerical limitations in consumption of fish from the Indian Lakes area (OU 2D).

3.3 SOURCES OF RELEASE

The mills along the Carson River and its tributaries have been identified as the primary sources of Hg contamination in the watershed. As noted for the upper Carson River and Lahontan Reservoir CSM segments, Hg-contaminated material was redistributed downstream to the lower Carson River before construction of Lahontan Dam, and since that time some Hg (and MeHg) has been transported downstream to the lower Carson River. Considerable amounts of Hg have reached the lower Carson River. Hg contamination of sediment, surface water, and biota are briefly summarized below.

3.3.1 Sediments

The area below the Lahontan Dam is a large, nearly flat, terminal basin about 20 by 60 miles in size. The upstream portion closer to the dam is called the Lahontan Valley, while the downstream, northeastern half of the basin is called the Carson Sink. To depths of 300 feet, the native near-surface sediments in the basin consist of fine to coarse lakebed and near-shore sediment (very fine sand and silt, with some gravel) laid down in Pleistocene-age Glacial Lake Lahontan; these native sediments contain low levels of Hg (0.04 ppm; Lico, 1992), considered to represent background levels for the area.

Cooper et al. (1985) reported mean Hg values for bottom sediment (including the river, irrigation canals, and drains) at five locations in the lower Carson River area ranging from 0.15 to 5.44 mg/kg (samples were collected on multiple dates at each location); they also collected samples from a dark-colored "mercury-rich layer" of the bank sediments at five locations, and reported mean values ranging from 0.20 to 9.39 mg/kg. Even the lowest of these values is considerably greater than the 0.04 mg/kg local background for mercury. Lico (1992) reported a somewhat lower mean Hg value of 0.23 mg/kg for 22 bottom-sediment samples collected from irrigation drains, with individual values ranging from 0.04 to 14 mg/kg.

A general observation noted in several of the sediment studies of the lower Carson River was that Hg concentrations were higher along channels of the river or wetland flow that were active during the mining period in the nineteenth century. Historic wetlands had higher Hg than constructed wetlands, while both were considerably higher in Hg than background sediments of the Lahontan Valley.

3.3.2 Surface Water

Total and MeHg concentrations have been characterized only for certain locations in the stretch of river channel and irrigation conveyances below Lahontan Reservoir, including an ongoing sampling program conducted by the USGS at one river gage station a short distance below the dam. Samples collected from irrigation drains showed eight samples analyzed for unfiltered total Hg with a mean of 750 ng/L (Hoffman et al., 1990), and 33 samples analyzed for filtered total Hg with a mean of 130 ng/L. Sampling of the lower Carson River by the Bureau of Reclamation showed unfiltered total Hg with a mean of 350 ng/L in 10 samples (Craft et al., 2005); filtered total Hg in these samples was much lower, with a mean value of 13.2 ng/L. At the Below-Lahontan USGS station, unfiltered total Hg has averaged 249 ng/L in 113 samples, and filtered total Hg has averaged 8.27 ng/L. Samples collected by Hoffman and Taylor (1998) during the record flood year of 1997 showed a mean value of 810 ng/L for unfiltered total Hg in 10 samples, with the highest results in the month after the flood in January; filtered samples were not collected.

The Hg and MeHg values from the various water-sampling efforts are broadly consistent, and show that, as noted for samples above the reservoir, total Hg is largely carried with the suspended sediment; in the two most-recent studies, only about 3% of total Hg has been in the dissolved fraction (assumed to be accurately represented by the filtered result). In contrast to samples from above the reservoir, samples from the lower Carson River are likely to be carrying a major fraction of their suspended solids as organic particulates (i.e., planktonic algae); a significant proportion of inorganic particulates of silt and clay is deposited in the quiescent waters of the reservoir, and does not reach the lower Carson. Finally, it appears that there may be higher total Hg in the irrigation drains of the lower Carson than in the samples from the river a short distance below the reservoir.

Less information is available about MeHg than about total Hg in water, but values appear to be somewhat lower than those in the upper Carson River. Samples collected from the lower Carson River during the flood year of 1997 had a mean value for unfiltered MeHg of 1.00 ng/L for four samples. At the Below-Lahontan USGS station, the mean value for unfiltered MeHg in 114 samples collected from 1997 to 2011 has been 1.14 ng/L, although this has been skewed by a small number of high values (up to 35.2 ng/L); the median of 0.38 ng/L is thus considered a more informative value for this location. Filtered MeHg in these samples has had a median of 0.15 ng/L. Thus, as observed elsewhere in the watershed, dissolved (filtered) MeHg has constituted a higher proportion of total MeHg (about 40%) than dissolved/filtered Hg relative to total Hg (about 3%).

Overall, Hg and MeHg concentrations in waters of the lower Carson River are significantly lower than in the upper Carson River. As discussed in the Lahontan Reservoir CSM segment, based on comparisons of Carson River water a short distance upstream and downstream of the reservoir, it appears that, on a long-term basis, the reservoir has retained about 90% of total Hg and 60% of MeHg that has been supplied to it.

As noted in the upper Carson River CSM segment, there appear to be strong seasonal patterns of Hg and MeHg concentration in the Carson River below the reservoir. In the USGS sampling program from 1997 to the present, the station just below Lahontan Reservoir commonly shows peaks in unfiltered total Hg in spring and summer, largely following suspended sediment values. In most years, MeHg (median 0.38 ng/L) attains elevated values of greater than 0.5 ng/L in July to September, with values exceeding 1 ng/L reported in five recent years (ranging up to 35.2 ng/L). As noted for the upper Carson River samples, these MeHg peaks have coincided with temperatures above 20 °C, and often with slightly depleted DO values (<6 mg/L). The late-summer increases in MeHg at the Below-Lahontan gage parallel those observed for the upper Carson River station at Weeks Bridge.

3.3.3 Biota

There are not as many Hg analyses of fish samples reported from the lower Carson River system as for fish from the upper Carson River or Lahontan Reservoir. Cooper et al. (1985) reported 78 fish samples from the Carson River at locations just below Lahontan Reservoir to just below Sagouspe Reservoir (just north of Fallon, and above the wetlands). Thirty-three (42%) of these samples exceeded the FDA action level of 1 ppm, which is a smaller proportion than for the upper Carson River at Fort Churchill, but similar to that for the Lahontan Reservoir. One site, the Sheckler Reservoir, had clearly lower fish Hg levels than the other lower Carson River locations in this study, as only one of the 21 fish collected there had Hg greater than 1 ppm. Sheckler Reservoir was constructed in the 1950s, and was not previously a river channel; as observed by others, Hg tends to be lower in the sediments and soils of such areas, which likely accounts for the low Hg in fish from this reservoir. Overall, as occurred for samples collected from the upper Carson River and the Lahontan Reservoir, there was a general pattern in the lower Carson of higher Hg levels in fish of higher trophic levels, such as walleye and bass; catfish and carp also had relatively high Hg, possibly related to their role as omnivorous bottom feeders. The highest fish Hg result for the lower Carson River was 2.85 ppm, for a carp from below the Sagouspe Reservoir, several miles above the wetlands of Indian Lakes.

There are no available Hg data for birds or for other biota than fish in the lower Carson River area. Except for fish, sampling of other biota in the area has focused farther downstream, in the wetlands of Carson Lake and the Stillwater Wildlife Refuge, which are covered in the CSM segment on OU 2D that follows.

3.4 TRANSFORMATION AND TRANSPORT MECHANISMS

As in the other segments of the Carson River Mercury Site discussed in the CSM, the form of Hg of greatest interest is MeHg, which is biologically active and bioaccumulative, with the most concern being for its accumulation in piscivorous fish as well as some omnivores such as catfish. Among other factors, reducing conditions along portions of the river, dissolved organic carbon, and seasonally elevated temperatures are likely to contribute to methylation of Hg.

As summarized in the previous section, Hg and MeHg are both present in sediments and water at elevated levels in both dissolved and particulate forms in this downstream portion of the Carson

River system. Based on Hg concentrations in sediment, a large quantity of Hg has migrated downstream to the lower Carson River. Since the completion of Lahontan Dam in 1915, Lahontan Reservoir has retained about 90% of the Hg that has been delivered to the reservoir; the record flood year of 1997 was an exception in that only approximately 80% of the Hg was retained, as more-turbid waters containing sediment-bound Hg were released in the weeks after the flood (Hoffman and Taylor, 1998). Most of the retained Hg and MeHg have been in particulate form. Partly as a result of the shorter period of transport (1860 to 1915) compared to upstream areas (1860 to the present), Hg concentrations in sediments of the lower Carson River generally are lower than those in the upper Carson River and Lahontan Reservoir. Results of 0.5 to 5 mg/kg (occasionally to 14 mg/kg) are typical in this downstream area, while concentrations of 1-25 mg/kg and higher are very common for the upstream segments.

Hg and MeHg levels in water samples from the lower Carson River also tend to be lower than those reported for the upper Carson River or the Lahontan Reservoir. This is partly due to the fact that Hg and MeHg are strongly associated with particulate matter. However, the overall lower levels of Hg and MeHg in sediment of the lower Carson River also tends to result in lower Hg and MeHg in water, in both filtered (dissolved) and unfiltered fractions.

Consistent with the generally lower levels of Hg and MeHg in lower Carson River sediments and surface waters compared to those in the upper Carson River and Lahontan Reservoir, Hg in biota also appears to be somewhat lower in the lower Carson River than in the upstream areas. However, the limited sampling results, for fish only, indicate that Hg is still present in nearly half of fish at levels above the FDA action limit of 1 ppm.

3.5 POTENTIAL EXPOSURE PATHWAYS TO POTENTIAL RECEPTORS

Figure 4 is a schematic illustration of the exposure pathway evaluation for the lower Carson River. There is no warning from the State of Nevada in effect regarding the consumption of fish from the lower Carson River, and thus residents and recreational users could be exposed to COPCs by ingestion of contaminated tissue of fish that have bioaccumulated residues of MeHg and total Hg. Potential exposures to soils and sediments could include incidental ingestion, dermal contact, and inhalation of soil particulates, such as from dry, abandoned channels of the lower portion of the river. As the river is now actively managed and flows below the Lahontan Dam are expected to continue to be relatively low, such abandoned channels are expected to remain dry. Burial of Hg- and MeHg-contaminated sediment, while not an exposure pathway, is a fate process that could serve to remove Hg and MeHg from the active zone of methylation and demethylation near the ground surface. While sedimentation is not proceeding at a rapid rate now that flows are controlled at low levels in the lower Carson River, it may be that older sediments are sufficiently buried by subsequent deposition that they can be considered inactive and permanently removed from the near-surface Hg cycle. As a result, burial is listed as a specific process on Figure 4.

Aquatic receptors (e.g., invertebrates, fish, frogs, and wildlife) could be potentially exposed to Hg or MeHg via ingestion and skin contact. Potential exposures of terrestrial and aquatic plants could occur through uptake of chemicals from soil, sediment, and surface water. If evidence of bioaccumulation is observed, then it is possible that bioaccumulation via terrestrial herbaceous vegetation, such as grasses or irrigated crops, could become a viable human or ecological pathway. Based on sampling conducted by various investigators, Hg concentrations in piscivorous and other fish in the lower Carson River have often been above the FDA action level for Hg of 1 ppm and the EPA consumption advisory limit of 0.3 ppm, with concentrations ranging up to 2.85 ppm.

4.0 LAHONTAN VALLEY WETLANDS AND WASHOE LAKE (OU2D)

The CSM for the Lahontan Valley wetlands and Washoe Lake portion of the Carson River Mercury Site summarizes the sources, release and transport mechanisms, exposure pathways, and ultimate receptors that are affected by Hg and MeHg in the environment. The Lahontan Valley wetlands segment encompasses that portion of the Carson River watershed downstream from the generally active-flowing portion of the Carson River and downstream from the irrigation drains of the Newlands irrigation project. Washoe Lake is included with the Lahontan Valley wetlands because it has some wetland areas within it and along some of its shores; despite being a lake, it differs from the Lahontan Reservoir in that it sometimes dries out completely, and is too shallow to develop seasonal stratification. Also unlike the Lahontan Reservoir, it does not have significant ongoing inputs of new stream-borne Hg; it is located in a separate watershed from the Carson River, and its Hg was released near its current disposition, when Comstock-era mills were operated along its shorelines. In these ways Washoe Lake is more similar to the Lahontan Valley wetlands than it is to either Lahontan Reservoir or the upper or lower Carson River segment of the Site.

This CSM is intended to convey the major themes of Hg distribution, transport, and environmental fate, as well as how humans and ecological receptors could come into contact with Hg, to support decisions about overall project direction (such as what steps may need to be taken to close any possible data gaps) and to assist with the preliminary screening of remedial alternatives for OU2.

4.1 ENVIRONMENTAL SETTING AND LAND USE

The Lahontan Valley wetlands are characterized by land reserved for use primarily as wetlands, although some portions such as at the Carson Lake pasture are used primarily for livestock grazing. Much of the wetlands are within the Stillwater and Fallon National Wildlife Refuges (NWRs) and the Carson Lake Wildlife Management Area (WMA) and the Stillwater Wildlife Management Area. These areas are used for recreational purposes (bird-watching, boating, camping, and hunting in portions of the refuges) and as natural areas (albeit modified by human manipulation of surface-water hydrology). The wetlands provide important migration, breeding, and wintering habitat for up to 1 million migratory birds, including waterfowl, shorebirds, colonial nesting water birds, and neotropical migratory birds. The Stillwater and Fallon refuges are part of the Lahontan Valley Shorebird Reserve, one of only 16 sites recognized for their international importance by the Western Hemispheric Shorebird Reserve Network.

Water enters the Lahontan Valley wetlands largely as drainage from irrigated fields, although direct flow from the Carson River occasionally accounts for some flow during high-flow years, when water in excess of agricultural needs is released from Lahontan Reservoir for water-management purposes. Irrigation drainage water is collected in deep drains and channeled downstream to a sequence of lakes, eventually ending up in the terminal wetlands. Irrigation drainage water tends to be more saline than water applied to fields. In some years, water ultimately may be delivered to the Carson Sink, an enclosed depression below 3,880 feet in elevation. However, extensive evaporation in the desert environment results in little to no water being delivered to Carson Sink in most years. Average annual precipitation in this part of the drainage basin is approximately 4 to 5 inches.

Fishing occurs in the wetlands in areas such as Indian Lakes, Foxtail Lake, and other lakes toward the upstream side of the wetlands complex. The Nevada State Health Division (Nevada SHD) health advisory against consumption of any fish caught from the Carson River from Dayton downstream to and including the Lahontan Reservoir (http://www.ndow.org/fish/health/, accessed August 25, 2011) does not apply to the Lahontan Valley wetlands; below the reservoir, limitations in fish consumption (one to three fish per month) are specified for several types of fish from Indian Lakes. Consequently, as Hg is still present in the wetlands at elevated levels (discussed below under Biota Sampling), human exposures to Hg may occur due to consumption of fish from water bodies of the Lahontan Valley wetlands.

Washoe Lake is a shallow lake located about 10 miles west of Dayton. While not located adjacent to the Lahontan Valley wetlands, it has been included with these wetlands for the purposes of the CSM, based on the fact that it is a shallow body of water that has wetlands along some of its shores; like portions of the terminal wetlands of the Lahontan Valley, it sometimes dries out completely. Unlike Lahontan Reservoir, Washoe Lake is too shallow to develop stratification in the summer months. Although variable in size, Washoe Lake is commonly about one by three miles in area. Its shallow depth has made it prone to desiccation; in recent years it has dried out completely in 1992, 1994, and 2004. A marshy area separates the two portions of the lake, which are referred to as Big and Little Washoe lakes; other margins of the lake host wetland vegetation. The lake drains to the north via Steamboat Creek, which in turn flows into the Truckee River. The lake is eutrophic, and is typically turbid due to its shallow depth and the generally high winds of the area. Approximately six mills were located along Washoe Lake, where mercury was used to amalgamate gold and silver in a process similar to that used at the mills near Dayton along the Carson River. The Nevada SHD has issued a health advisory recommending no consumption of white bass, carp, or Sacramento perch from Big and Little Washoe lakes (http://www.ndow.org/fish/health/, accessed 9/22/11). Downstream from Washoe

Lake, Nevada SHD has recommended limitations in the consumption of several types of fish from Steamboat Creek and from the Truckee River below Reno (below Steamboat Creek).

4.2 CHEMICALS OF POTENTIAL CONCERN

The primary COPC for all media in this segment of the Site is Hg, including its MeHg form. As noted above, elevated concentrations of Hg and MeHg have resulted in a comprehensive state health advisory against consumption of fish caught upstream from the Lahontan Valley wetlands, and for white bass caught in Big and Little Washoe lakes, as well as a limitation on consumption of fish from Indian Lakes.

4.3 SOURCES OF RELEASE

Comstock mining-era mills along the Carson River and its tributaries have been identified as the primary sources of Hg contamination in the Carson River watershed; there were also about six mills near the western shore of Washoe Lake, which were the likely Hg sources to Washoe Lake, located in the Truckee River watershed (U.S. EPA, 2011). Since mining began in 1859, Hg-bearing sediment in the form of Hg-silver-gold amalgam has been susceptible to erosion and deposition downstream from the points of release near the mills. A significant amount of Hg migrated downstream into the Lahontan Valley before completion of the Lahontan Dam in 1915; Lahontan Reservoir since that time has served as a settling basin in which much of the particulate-bound fraction of Hg and MeHg has settled, although downstream migration of Hg and MeHg in both solid and liquid phases continues to some degree. A brief summary of Hg data is presented below.

4.3.1 Sediments

4.3.1.1 Sediments of Lahontan Valley Wetlands

The area below the Lahontan Dam is a large, nearly flat, terminal basin about 20 by 60 miles in size. The upstream portion near the dam is called the Lahontan Valley, while the downstream, northeastern half of the basin is called the Carson Sink. To depths of 300 feet, the native near-surface sediments in the basin consist of fine to coarse lake-bed and near-shore sediments (very fine sand and silt, with some gravel) laid down in Pleistocene-age Glacial Lake Lahontan; these sediments contain low levels of mercury (0.04 ppm; Lico, 1992), and are considered to represent the local background levels of Hg.

Cooper et al. (1985) reported mean Hg values for bottom sediment at two locations in the Stillwater NWR as non-detect (ND) and 1.76 mg/kg (samples were collected on multiple dates at each location); at both sites, a dark-colored Hg-rich layer, sampled separately, showed mean Hg results of ND and 4.89 mg/kg. Hoffman et al. (1990) collected eight bottom-sediment samples from wetlands at Carson Lake WMA and Stillwater NWR and reported values ranging as high as 18 mg/kg, with a median Hg value of 3.80 mg/kg.

Ninety soil samples (30 each from depths of 0-6 inches, 21-27 inches, and 57-63 inches) were collected from the Carson Lake pasture area and analyzed by CH2M Hill for Hg (unpublished pages entitled "Carson Lake Pasture," 2/20/93). In these soils, above-background values of Hg are largely limited to shallow depths: shallow samples had a mean value of 4.77 mg/kg, mid-depth samples had a mean of 0.71 mg/kg, and deep samples had a mean of 0.14 mg/kg. Another 27 soil samples were collected from the Indian Lakes area, 23 of which were from 0-6 inches, and four of which were from 21-27 inches (unpublished pages entitled "Indian Lakes Soil Samples," 6/11/93). The mean for the 0-to-6-inch samples was 0.54 mg/kg, while the mean for the 21-to-27-inch samples was 0.16 mg/kg. The difference between the Hg concentrations in the Carson Lake pasture soils and the Indian Lakes soils is likely due to the fact that the Carson Lake pasture received uncontrolled flow from the upper Carson River during the mining period, being located near the terminus of the South Branch of the Carson River before the completion of Lahontan Dam; in contrast, the Indian Lakes area was some distance from the nearest river channel (the Main Branch of the Carson River) during this period.

Hoffman et al. (1998) collected five bottom-sediment samples from wetland environments in or near Stillwater NWR and Carson Lake WMA and reported values ranging as high as 4.11 mg/kg for total Hg, with a median value of 1.37 mg/kg; they also analyzed MeHg in these five sediment samples, and reported values ranging up to 5.44 ug/kg, with a median of 1.38 ug/kg.

Tuttle et al. (2001) characterized mercury in the Lahontan Valley wetlands, and sampled historic wetlands as well as some of the constructed wetlands. In 13 sediment samples of historic wetlands in the Stillwater NWR, median Hg was 0.762 mg/kg, while the median for MeHg was

1.1 ug/kg. In nine sediment samples from the constructed wetlands at Stillwater NWR, median Hg was 0.152 mg/kg, about five times lower than at the historical wetlands, while the median for MeHg was 0.79 ug/kg. In both areas, MeHg was correlated with total Hg in sediments, and the percentage of Hg that was MeHg was higher in sediments of constructed wetlands (median of 0.41%) than in historic wetlands (median of 0.2%); this difference was also reflected in elevated MeHg levels in the biota of constructed wetlands (discussed below). Tuttle et al. (2001) also collected two bottom-sediment samples from wetlands in the Fallon NWR (near the mouth of the North Fork of the Carson River), and reported significantly higher total Hg results at 7.16 and 21.8 mg/kg; however, MeHg was present at 0.2 and 1.2 ug/kg, respectively, in these samples, at a much lower proportion of total Hg (mean of 0.004% of total Hg) than in the Stillwater NWR samples.

Hg values in sediments of the Lahontan Valley wetlands, typically in the 0.5 to 5 mg/kg range, are lower than those of the floodplain sediments of the upper Carson River and sediments of the Lahontan Reservoir, but are considerably higher than background (approximately 0.04 mg/kg Hg) for the area. As noted above, historic wetlands and river channels had higher Hg than constructed wetlands and areas not located along the pre-Lahontan Dam river channels, while both were considerably higher in Hg than native background sediments of the Lahontan Valley.

4.3.1.2 Sediments of Washoe Lake and Downstream Waters

Sediment sampling was conducted by the NDEP in 1987 and 1988 in Big and Little Washoe lakes, respectively. Hg in Big Washoe Lake sediments ranged from ND to 7.40 mg/kg, with a median of 4.30 mg/kg. Little Washoe Lake sediments had much higher values, ranging from 39.8 to 100.3 mg/kg, with a mean of 60.0 mg/kg (unpublished data from NDEP, 1988). In Steamboat Creek downstream from Washoe Lake, Hg levels in creek and creek-bank sediments ranged from <0.01 to 21.43 mg/kg (Stamenkovic et al., 2004). Most of these Hg values are well above what have been considered background Hg levels in the general area (<0.1 mg/kg; Craft et al., 2005), but are similar to those reported for sediments from the Carson River system from Dayton to the Lahontan Valley wetlands. In another study, Hg levels in Steamboat Creek sediments ranged from 0.26 to 10.2 mg/kg; MeHg concentrations were not available, but were reported as being higher in wetland sediments along Steamboat Creek than along creek banks or the creek channel (Blum et al., 2001). Farther downstream, somewhat elevated Hg levels were reported in portions of the Truckee River downstream from the mouth of Steamboat Creek; while values were not nearly as high as those in the Carson River, Hg concentrations in sediments downstream from Steamboat Creek were reported to be 20-25 times higher than those at an upstream background site (Lawrence, 1998). The source of Hg in the Washoe Lake sediments and downstream waters is likely to have been the Comstock-era mills that operated near the shores of Washoe Lake, although Hg in Steamboat Creek and downstream may have originated in part from geothermal discharge at the Steamboat Springs area along Steamboat Creek (Lawrence, 1998).

4.3.2 Surface Waters

4.3.2.1 Surface Waters of Lahontan Valley Wetlands

In surface water samples, total Hg and MeHg concentrations are characterized only for certain locations in wetlands below Lahontan Reservoir. Analysis of 34 water samples collected from the lakes and canals showed filtered total Hg with a median of 100 ng/L (Hoffman et al., 1990); MeHg was not analyzed. Hoffman and Thomas (2000) collected five unfiltered surface water samples from wetland environments in or near Stillwater NWR and Carson Lake WMA, and reported total Hg values ranging as high as 370 ng/L, with a median of 221 ng/L; they also analyzed MeHg in these five samples, and reported values ranging up to 3.14 ng/L, with a median value of 0.93 ng/L.

In their study of mercury in the Lahontan Valley wetlands, Tuttle et al. (2001) collected six water samples from constructed wetlands in the Stillwater NWR, obtaining a median value for total Hg in unfiltered samples of 60 ng/L and a median for MeHg of 3.3 ng/L; the median percentage of MeHg relative to total Hg was 8.0%. They also collected 10 surface water samples from historic wetlands in the Stillwater NWR, obtaining a median value for total Hg in unfiltered samples of 113 ng/L and a median for MeHg of 2.1 ng/L; median percentage of MeHg relative to total Hg was 1.9%. DO tended to be lower in the constructed wetlands (median 5.8 mg/L) than in the historical wetlands (median 9.1 mg/L), possibly accounting for an environment more amenable to Hg methylation in the constructed wetlands.

Similar to the pattern for sediment samples noted in the preceding section, water samples from Fallon NWR have had higher total Hg but much lower fractions of MeHg to total Hg (median 0.3%) compared to the constructed and historic wetlands of Stillwater NWR. For a number of years, Fallon NWR has had much less water than has Stillwater NWR, and transformation of Hg to MeHg is likely to be less extensive under the drier conditions.

4.3.2.2 Surface Waters of Washoe Lake and Downstream Waters

Six surface water samples were collected from Washoe Lake in 1987, with ND results. However, the reporting limit for Hg in these samples was 0.5 ug/L (500 ng/L), much higher than what is considered useful in assessing Hg. As a result, the available data for surface water samples from Washoe Lake are of limited value. At Steamboat Creek downstream from Washoe Lake, however, more-recent surface water data are available, and show unfiltered total Hg levels of 82 to 419 ng/L and MeHg levels of 0.63 to 1.4 ng/L (Blum et al., 2001). These values are generally similar to those reported for the Lahontan Valley wetlands. Limited data for the Truckee River suggest fairly low concentrations in at least part of its reach downstream from the mouth of Steamboat Creek, based on values of 4.0 to 4.4 ng/L for unfiltered total Hg where the Truckee River Canal empties into Lahontan Reservoir (Wayne et al., 1996).

4.3.3 Biota

4.3.3.1 Biota of Lahontan Valley Wetlands

There are not as many Hg analyses of fish samples reported from the Lahontan Valley wetlands as for fish from the upper Carson River or Lahontan Reservoir, as populations of game fish are fairly low in these waters. As with the other CSM segments, all Hg biota values are wet-weight basis except where indicated otherwise. Cooper et al. (1985) reported 24 fish samples from the Indian Lakes area a few miles west of Stillwater NWR, and 14 (58%) of these samples exceeded the FDA action level of 1 ppm (wet weight) Hg. This is a smaller proportion than the 88% reported in the same study for the upper Carson at Fort Churchill, but roughly similar to that for Lahontan Reservoir and for sites in the lower Carson River. A few miles to the north, Cooper et al. (1985) reported 36 fish samples for two sites in and north of Fallon NWR, with only eight (22%) of these samples exceeding 1 ppm Hg.

Hoffman et al. (1990) collected 53 fish of six species from Stillwater NWR and Carson Lake WMA in 1986-1987, and reported the results in terms of dry weight (because of water content, wet weight concentrations are generally lower by a factor of about four compared to dry weight values). Mean values for the four species that had more than one sample each ranged from 0.36 to 1.21 mg/kg on a dry-weight basis; individual Hg values ranged as high as 5.7 ppm Hg, dry weight, for a Sacramento perch, and 2.8 ppm Hg, dry weight, for a mosquitofish.

Tuttle (1992) reported on Hg levels in 43 fish of four types collected from five lakes of the Indian Lakes system in 1990. Mean values for each species were reported, and ranged from 0.5 to 2.7 mg/kg (wet weight); levels were greater than the FDA action level of 1 mg/kg for white bass in all five lakes, and for white crappie in one lake. More-recent sampling reported by NDEP for Indian Lakes in 2009, reported as wet-weight concentrations, listed 11 fish of three species, none of which exceeded the FDA action level of 1 ppm Hg; two of the fish had greater than 0.5 ppm Hg. Overall, when fish of similar type and size are compared, Hg levels in fish of the Lahontan Valley wetlands have often been somewhat lower than in fish from Lahontan Reservoir.

A wide range of Hg data for other biota have been reported from Stillwater NWR, Carson Lake WMA, and Indian Lakes, in five separate studies (Hoffman et al., 1990; Hallock and Hallock, 1993; Tuttle and Thodal, 1998; Tuttle et al., 2001; Henny et al., 2002). Many types of biota have been sampled, and data were often provided only in summary form. However, in general, it appears that Hg impacts are widespread in biota of the Lahontan Valley wetlands: algae have ranged up to 10.4 ppm, aquatic plants up to 2.4 ppm (dry weight), insects up to 5.4 ppm (dry weight), brine shrimp up to 1.13 ppm, aquatic bird eggs up to 6.2 ppm, aquatic bird livers up to 31 ppm, and aquatic bird muscle up to 16 ppm. The peak and mean Hg values for eggs of several species significantly exceeded the 0.83 mg/kg (ppm) effect level delineated by Heinz (1979). The mean and peak Hg values for livers of several species were significantly above the effect-level of 4.3 mg/kg as defined by Heinz (1979). In their detailed study of corixids (bottom-dwelling water boatmen that eat aquatic plants and algae) from the Lahontan Valley wetlands, Tuttle et al. (2001) found that Hg in invertebrates correlated with MeHg in sediments; in addition, they noted that bioaccumulation to these invertebrates was higher in constructed wetlands than in the historic wetlands that received Carson River flow before completion of Lahontan Dam, indicating a possible influence of Hg bioavailability in the newer (constructed) wetlands.

Overall, as observed for samples collected from the other three segments of the Carson River system, in the Lahontan Valley wetlands there is a general pattern of higher Hg levels in fish of higher trophic levels, such as bass and perch; carp also had relatively high Hg, possibly related to their role as bottom feeders. For many species of biota (insects, fish, and waterfowl), the highest Hg results have been reported for samples from the Carson Lake WMA in the southernmost part of the Lahontan Valley. Nevada SHD issued a public-health warning for the consumption of shoveler ducks from Carson Lake in 1989 due to Hg levels. The Carson Lake area received flow down the South Branch of the Carson River during the period of mining, accounting for Hg-contaminated sediments in the area. As observed for fish, biomagnification appears to have occurred in the avian food chain, with aquatic birds having generally higher Hg values than plants or invertebrates.

4.3.3.2 Biota of Washoe Lake

Hg data for fish from Washoe Lake are reported for two distinct periods. NDEP reported data for 122 fish of six species collected in the summer of 1987. Of the 80 fish from Big Washoe Lake, only six (8%) exceeded the FDA action level of 1 ppm (wet weight) Hg. Of the 42 fish caught in Little Washoe Lake, six (14%) exceeded the FDA action level of 1 ppm Hg. The highest value, 2.3 ppm, was for a white bass. In 2005 to 2008, 25 fish of three varieties were collected from Big and Little Washoe lakes and analyzed for Hg. Mean values were reported for each species and each lake, and ranged from 0.63 to 7.37 ppm wet weight, with most values above the FDA action level of 1 ppm; the three bass from Big Washoe Lake had the highest mean value. The Nevada SHD has issued a health advisory recommending no consumption of white bass, carp, or Sacramento perch from Big and Little Washoe lakes (http://www.ndow.org/fish/health/, accessed 9/22/11), and also lists recommendations for limited consumption of several types of fish from downstream waters (Steamboat Creek and the Truckee River below Reno).

Limited sampling of fish from the Truckee River downstream of Reno (and presumably affected by influx from Washoe Lake via Steamboat Creek) shows relatively low levels of Hg in carp (mean of 0.30 mg/kg in six individuals caught in 2006; unpublished NDEP data). Other studies have reported higher Hg levels in fish downstream of the point where Steamboat Creek empties into the Truckee River (mostly in the range of 0.1 to 0.65 mg/kg) compared to fish upstream from the confluence (less than 0.1 mg/kg; Gustin et al., 2005).

As found in the Lahontan Valley wetlands, Hg levels in fish from Washoe Lake generally correlated with size and with trophic level. The fish Hg results were considerably higher in the samples collected from 2005 to 2008 than in the 1987 samples. Some of the difference is due to fish size, as none of the white bass collected in 1987 exceeded 10 inches in length, while the later white bass specimens ranged from 13.6 to 15 inches. However, the carp from the two time periods were mostly of the same size, while Hg levels increased by a factor of at least two. The reason for this increase is unknown, although a possible reason may be increased methylation in 2005-2008, associated with re-wetting of the sediment after the lake had dried out in 2004. Hg effects on biota in Steamboat Creek and the Truckee River, downstream from Washoe Lake, are limited, with fish having only slightly elevated Hg contents (Hg levels are up to 0.65 mg/kg).

4.4 TRANSFORMATION AND TRANSPORT MECHANISMS

As in the other segments discussed in the CSM, the form of Hg of greatest concern in the Lahontan Valley wetlands is MeHg, which is biologically active and bioaccumulative, with significant concern being for accumulation in piscivorous fish, as well as some bottom-feeders such as carp. One difference for the Lahontan Valley wetlands is that waterfowl are abundant in this area, and their diets are likely to include Hg-contaminated plants and animals. Tuttle et al. (2001) found a strong correlation of Hg levels in corixids with MeHg in sediment, but not with MeHg in water; in addition, Hg levels in these invertebrates were distinctly greater in constructed wetlands than in historic wetlands. While MeHg values in the sediments of historic and constructed wetlands, there may be higher Hg bioavailability in the constructed wetlands (these wetlands are newer than the historic wetlands).

As summarized above, Hg and MeHg are both present at above-background levels in sediments of these terminal wetlands of the Carson River system. Since the completion of Lahontan Dam in 1915, the Lahontan Reservoir has retained most of the Hg (about 90%, based on sampling from late 1997 to 2010) and MeHg (about 60%) that have been delivered to the reservoir. Largely due to the shorter period of uncontrolled flow and transport to the wetlands (1859 to 1915) compared to upstream areas (1859 to the present), Hg concentrations in sediments of the Lahontan Valley wetlands are generally lower than in the upper Carson River and Lahontan Reservoir; results of 0.5-5 mg/kg are typical of this downstream area, while Hg is often much higher in sediments of the upper Carson and Lahontan Reservoir. Similar levels of Hg are present in Washoe Lake.

Unfiltered Hg and MeHg levels in surface water samples from the Lahontan Valley wetlands also tend to be lower than those reported for the upper Carson River or the Lahontan Reservoir. This is partly due to the fact that Hg and MeHg are strongly associated with particulate matter, and the overall lower levels of Hg and MeHg in sediment of the wetlands tend to result in lower Hg and MeHg in water. Dissolved Hg and MeHg are also considerably lower than levels of these parameters in the upstream areas. Reliable surface water Hg analyses for Washoe Lake are lacking, as the only available samples were analyzed at a much higher reporting limit (500 ng/L) than typically achieved for recent Hg studies.

Consistent with the generally lower levels of Hg and MeHg in the lower Carson River (OU 2C) sediments and surface waters (compared to the upper Carson River and the Lahontan Reservoir), Hg in fish in the Lahontan Valley wetlands (OU 2D) also appears to be somewhat lower than in the upstream areas. However, the sampling results for fish indicate that Hg is still present in some fish (especially those from the Indian Lakes) at levels above the FDA action limit of 1 ppm. For other biota, including algae and the eggs, livers, and muscle of aquatic birds, Hg concentrations vary, but range upwards to levels above those reported for fish. Where higher MeHg levels have been identified in sediment, they appear to correlate with elevated Hg levels in certain invertebrates, and presumably pass upward through the aquatic food chain, ultimately leading to relatively high Hg levels in aquatic birds that feed in the wetlands.

Hg in fish from Washoe Lake has varied through the years, possibly related to the highly varied lake conditions (ranging to complete desiccation in 1992, 1994, and 2004). As has been reported for certain other Hg sites, re-flooding of the lake due to increased precipitation after 2004 may have created conditions amenable to Hg methylation, accounting for the much higher levels of Hg in fish collected from 2005 to 2008.

4.5 POTENTIAL EXPOSURE PATHWAYS TO POTENTIAL RECEPTORS

Figure 5 is a schematic illustration of the exposure pathway evaluation for the Lahontan Valley wetlands and Washoe Lake. There is only a recommendation from the Nevada SHD as to the number of several fish varieties that should be consumed from a portion of these wetlands (at Indian Lakes), and thus residents and recreational users could be exposed to COPCs by ingestion of contaminated tissue of fish or birds from the wetlands in which MeHg and total Hg have bioaccumulated. The state has posted a warning, however, about consumption of white bass from Big and Little Washoe lakes (http://www.ndow.org/fish/health/, accessed Sept. 22, 2011). Other potential exposures could include incidental ingestion of or dermal contact with soils and sediments, and inhalation of soil particulates (such as could be emitted from portions of the wetlands or Washoe Lake during droughts). Burial of Hg- and MeHg-contaminated sediment, while not an exposure pathway, is a fate process that could serve to remove Hg and MeHg from the active zone of methylation and demethylation near the ground surface. While sedimentation is not proceeding at a rapid rate now that flows are controlled at low levels in the wetlands, it may be that older sediments are sufficiently buried by subsequent deposition so that they can be considered inactive and permanently removed from the near-surface Hg cycle. As a result, burial is listed as a specific process in Figure 5.

Aquatic receptors (e.g., invertebrates, fish, frogs, and waterfowl) in both the Lahontan Valley wetlands and Washoe Lake could be exposed to Hg or MeHg via ingestion, skin contact, and predation. Potential exposures of terrestrial and aquatic plants could occur through uptake of chemicals from soil, sediment, and surface water. Hg bioaccumulation via terrestrial herbaceous vegetation, such as grasses or irrigated crops, may be a viable human or ecological pathway, as cattle and, ultimately, humans could be exposed to Hg via cattle grazing at Carson Lake pastureland areas. Based on sampling conducted by various investigators, Hg concentrations in piscivorous and other fish in the Lahontan Valley wetlands have occasionally been above the FDA action level for Hg of 1 ppm and the EPA MeHg fish tissue criterion of 0.3 ppm (U.S. EPA, 2001), with concentrations in fish ranging up to 2.7 ppm (wet weight) in the Lahontan Valley wetlands. Data are limited for Washoe Lake, but Hg in fish there has been largely greater than the FDA action level in recent years, ranging up to 8.8 mg/kg for a white bass in Washoe Lake.

5.0 REFERENCES CITED

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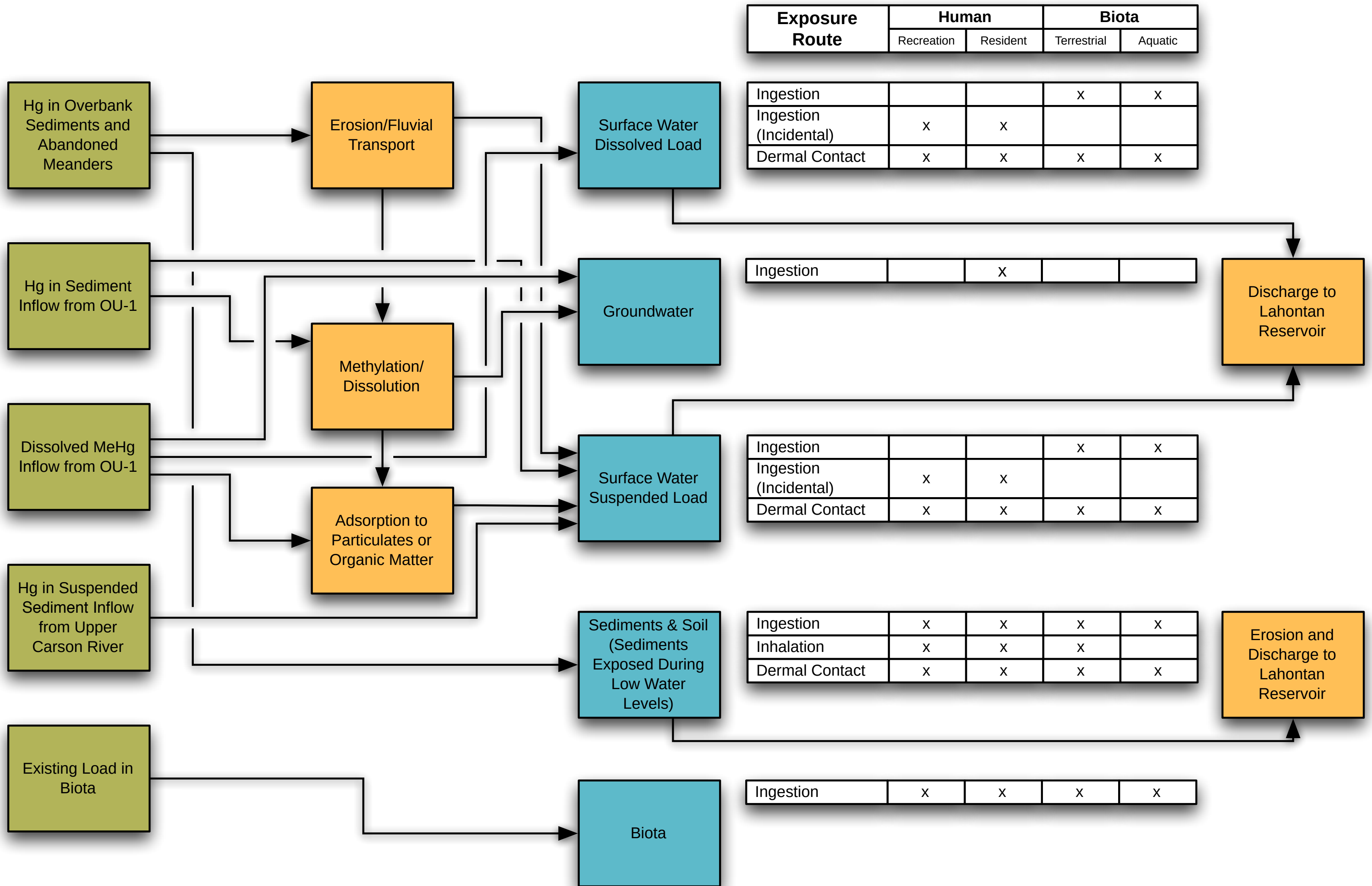

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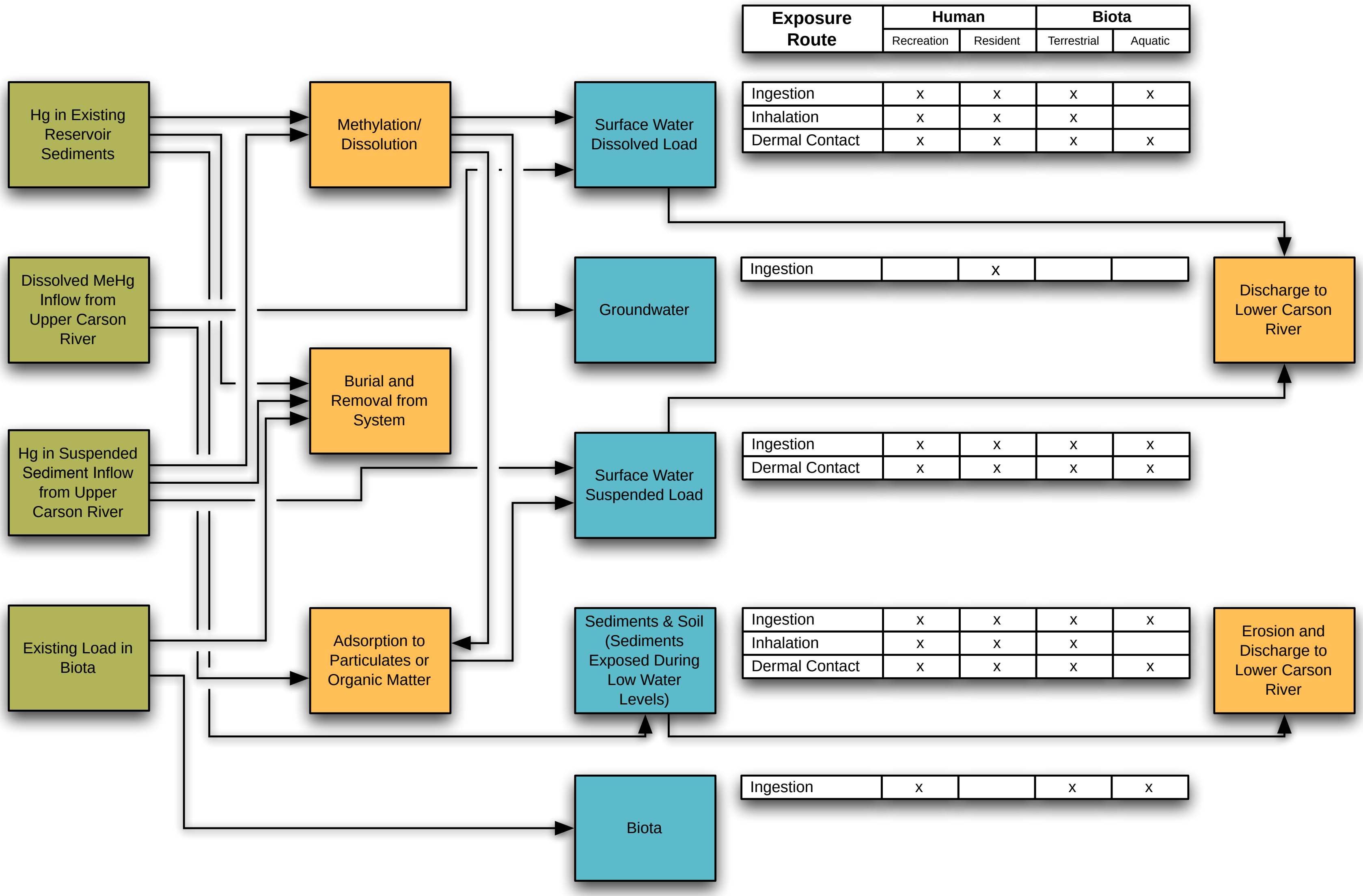
Carson River Mercury Site
Carson Drainage and Washoe Valley, Northwestern Nevada
U.S. Environmental Protection Agency, Region 9

FIGURE 1
Conceptual Site Model
Upper Carson River (OU 2A)



Exposure Route	Human		Biota	
	Recreation	Resident	Terrestrial	Aquatic
Surface Water Dissolved Load				
Ingestion	x	x	x	x
Inhalation	x	x	x	
Dermal Contact	x	x	x	x
Groundwater				
Ingestion		x		
Surface Water Suspended Load				
Ingestion	x	x	x	x
Dermal Contact	x	x	x	x
Sediments & Soil				
Ingestion	x	x	x	x
Inhalation	x	x	x	
Dermal Contact	x	x	x	x
Biota				
Ingestion	x		x	x

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Carson River Mercury Site
Carson Drainage and Washoe Valley, Northwestern Nevada
U.S. Environmental Protection Agency, Region 9

FIGURE 2
Conceptual Site Model
Lahontan Reservoir (OU 2B)

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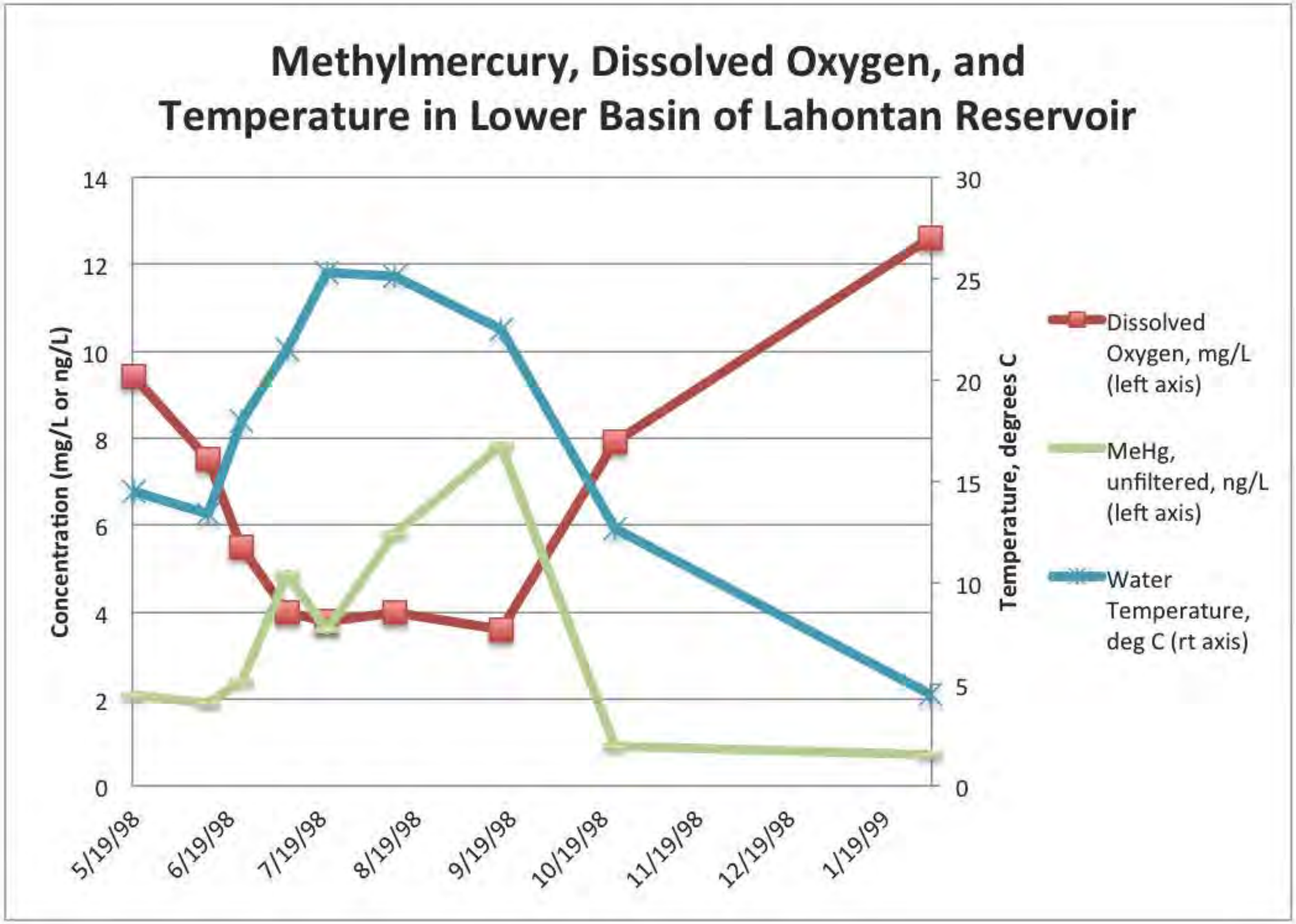
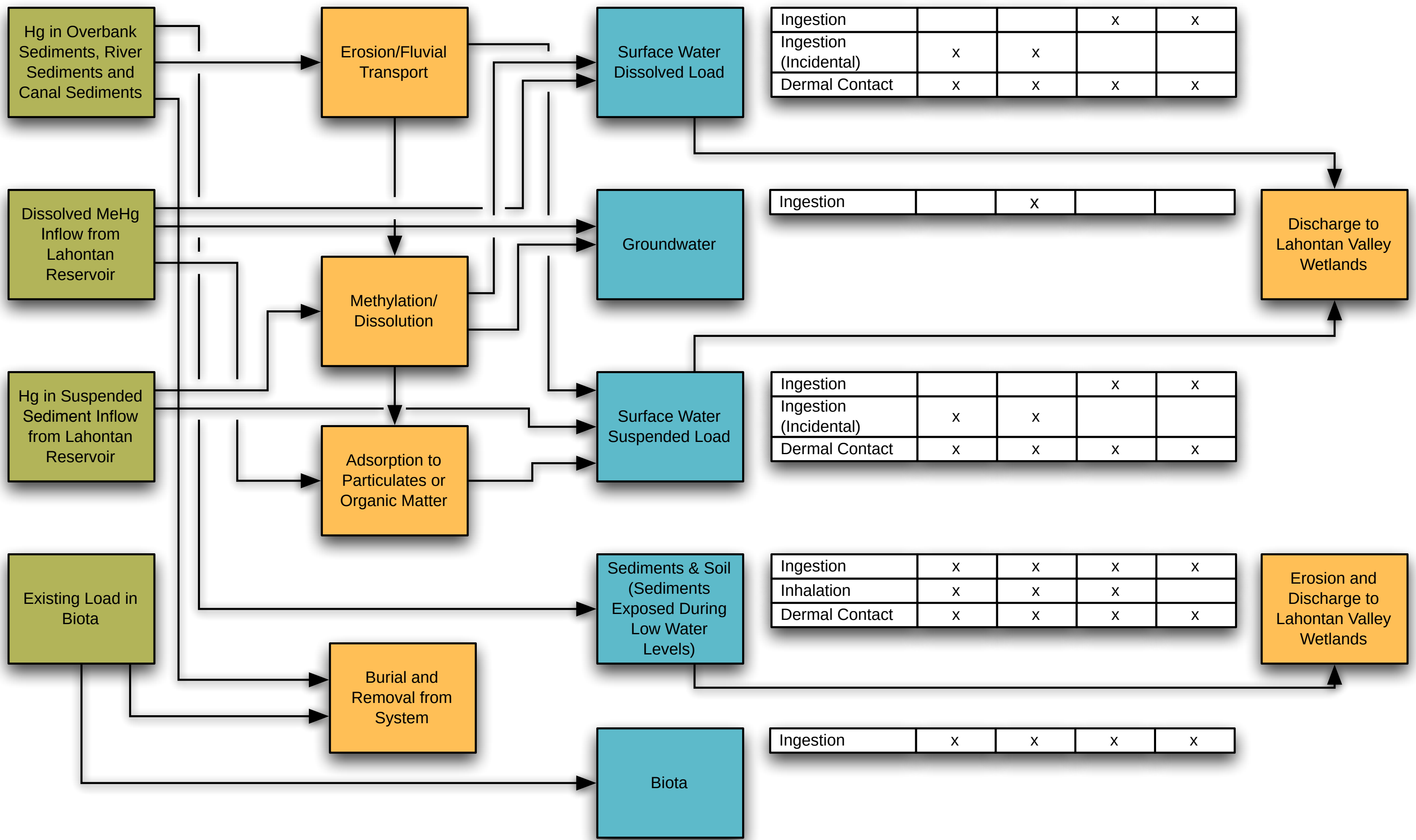


Carson River Mercury Site
Carson Drainage and Washoe Valley, Northwestern Nevada
U.S. Environmental Protection Agency, Region 9

FIGURE 3
Trends in Water Chemistry
Lahontan Reservoir (OU 2B)



Surface Water Dissolved Load

Exposure Route	Human: Recreation	Human: Resident	Biota: Terrestrial	Biota: Aquatic
Ingestion			x	x
Ingestion (Incidental)	x	x		
Dermal Contact	x	x	x	x

Groundwater

Exposure Route	Human: Recreation	Human: Resident	Biota: Terrestrial	Biota: Aquatic
Ingestion		x		

Surface Water Suspended Load

Exposure Route	Human: Recreation	Human: Resident	Biota: Terrestrial	Biota: Aquatic
Ingestion			x	x
Ingestion (Incidental)	x	x		
Dermal Contact	x	x	x	x

Sediments & Soil

Exposure Route	Human: Recreation	Human: Resident	Biota: Terrestrial	Biota: Aquatic
Ingestion	x	x	x	x
Inhalation	x	x	x	
Dermal Contact	x	x	x	x

Biota

Exposure Route	Human: Recreation	Human: Resident	Biota: Terrestrial	Biota: Aquatic
Ingestion	x	x	x	x

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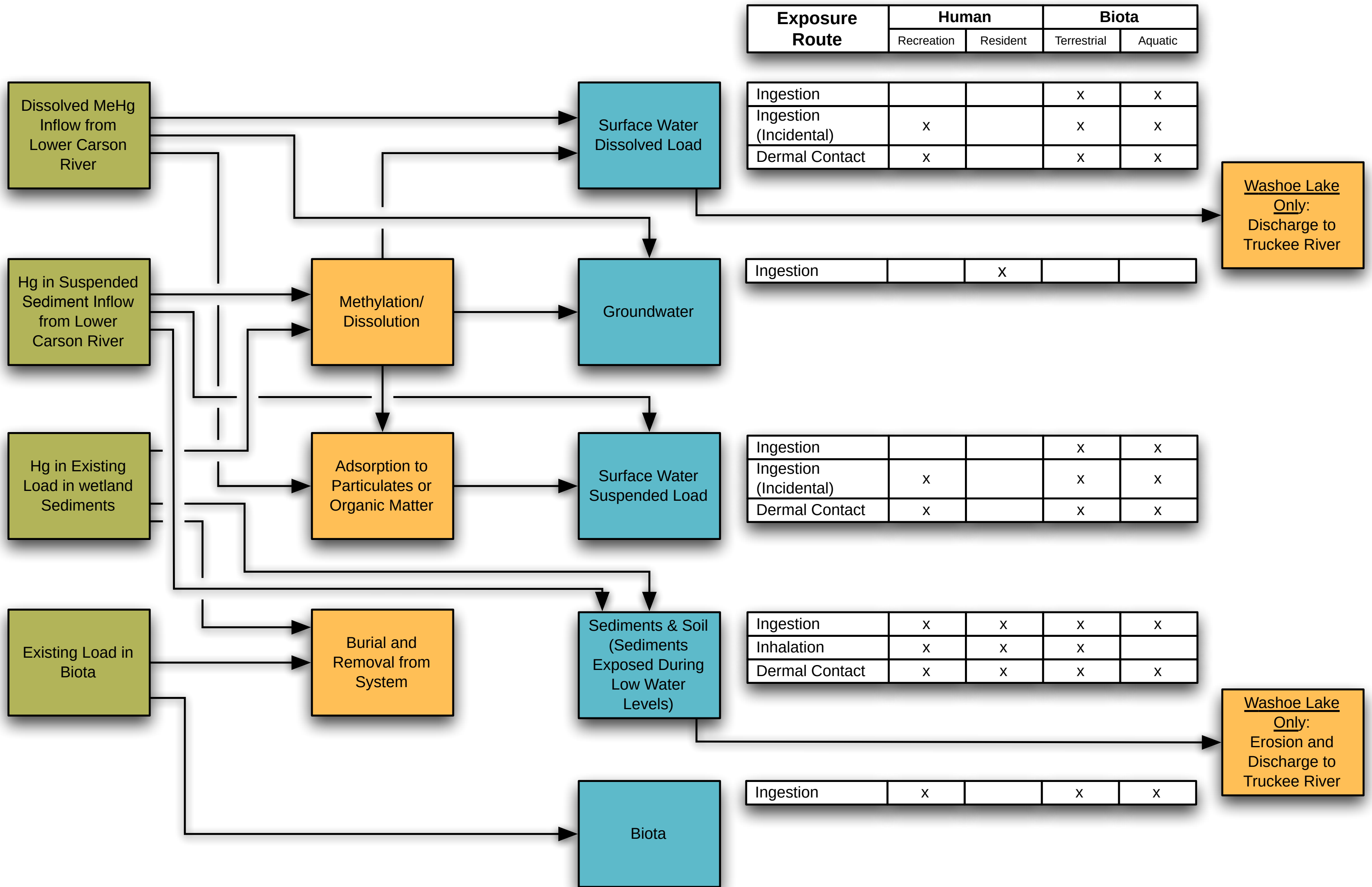
Carson River Mercury Site
Carson Drainage and Washoe Valley, Northwestern Nevada
U.S. Environmental Protection Agency, Region 9

FIGURE 4
Conceptual Site Model
Lower Carson River (OU 2C)



Medium	Exposure Route	Human Recreation	Human Resident	Biota Terrestrial	Biota Aquatic
Surface Water Dissolved Load	Ingestion			x	x
	Ingestion (Incidental)	x		x	x
	Dermal Contact	x		x	x
Groundwater	Ingestion		x		
Surface Water Suspended Load	Ingestion			x	x
	Ingestion (Incidental)	x		x	x
	Dermal Contact	x		x	x
Sediments & Soil	Ingestion	x	x	x	x
	Inhalation	x	x	x	
	Dermal Contact	x	x	x	x
Biota	Ingestion	x		x	x

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Carson River Mercury Site
Carson Drainage and Washoe Valley, Northwestern Nevada
U.S. Environmental Protection Agency, Region 9

FIGURE 5
Conceptual Site Model
Lahontan Wetlands (OU 2D)

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